UNITED STATES DISTRICT COURT

SOUTHERN DISTRICT OF TEXAS

HOUSTON DIVISION

ORIGINAL

Kenneth Davidson, et al.,

Plaintiffs,

V. CASE NO.4:15-cv-00827

Rockwell International Corporation, et al.,

Defendants.

DEPOSITION OF DON HANSEN, 11815 JUSTICE AVENUE, BATON ROUGE, LOUISIANA 70816, taken at the OFFICES OF DEGRAVELLES, PALMINTIER, HOLTHAUS & FRUGE, 618 MAIN STREET, BATON ROUGE, LOUISIANA 70801, in the above-entitled cause on the 22nd day of March, 2016.

APPEARANCES:

DEGRAVELLES, PALMINTIER, HALTHAUSS & FRUGE
BY: MICHAEL C. PALMINTIER, ESQ.
618 MAIN STREET
BATON ROUGE, LOUISIANA 70801
ATTORNEY REPRESENTING PLAINTIFFS,
KENNETH DAVIDSON, ET AL

ARNOLD & PORTER, LLP
BY: CHRISTOPHER M. ODELL, ESQ.
700 LOUISIANA STREET, SUITE 1600
HOUSTON, LOUISIANA 77002
E-MAIL: Christopher.odell@aporter.com
TELEPHONE: (713) 576-2400
FACSIMILE: (713) 576-2499
ATTORNEY REPRESENTING DEFENDANTS,
FAIRCHILD CONTROLS CORPORATION

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REPORTED BY:

CYNTHIA M. GRIJALVA, CCR, RPR

CERTIFIED COURT REPORTER

S T I P U L A T I O N

IT IS HEREBY STIPULATED AND AGREED by and between counsel for the parties hereto that the deposition of the aforementioned witness is hereby being taken under the Louisiana Code of Civil Procedure, Article 1421, et seq., for all purposes, in accordance with law;

That the formalities of reading and signing are NOT specifically waived;

That the formalities of sealing, certification and filing are specifically waived;

That all objections, save those as to form of the question and the responsiveness of the answer, are hereby reserved until such time as this deposition, or any part thereof, may be used or sought to be used in evidence.

* * * *

CYNTHIA M. GRIJALVA, Certified Court Reporter, in and for the Parish of East Baton Rouge, State of Louisiana, officiated in administering the oath to the witness.

DON HANSEN,
11815 JUSTICE AVENUE, BATON ROUGE, LOUISIANA 70816 after having first been duly sworn by the above-mentioned Court Reporter did testify as follows:

EXAMINATION

BY MR. ODELL:

Q. Good morning, Mr. Hansen.
A. Good morning.
Q. Would you please state you full name for the record.
A. Donald Earl Hansen.
Q. Mr. Hansen, my name is Chris Odell and I'm an attorney for Fairchild Controls Corporation, which is a defendant in a lawsuit pending in Houston, Texas, that's been brought by Kenneth Davidson, Tom Farmer and several other plaintiffs. You understand that you've been designated as an expert to testify on behalf of those plaintiffs in that case?
A. I think so, yes.
Q. And you understand you're here to give your deposition today in connection with your opinions in that case?
A. Yes.

Q. You've given depositions before have you not?
A. Yes.
Q. Do you know approximately how many times?
A. I do not.
Q. More than a dozen?
A. Yes.
Q. And so you're generally familiar with the procedure and how a deposition works and so forth?
A. I believe so.
Q. Just as a reminder, we can take a break whenever you like as long as there's not a question pending. And if I ask you a question and you respond to it, I'm going to assume you understood my question unless you tell me so; is that fair?
A. Yes.
Q. This lawsuit involves a cabin fume event on a Turbo Commander 690A aircraft in 2011; is that correct?
A. Yes.
Q. And have you ever flown on a Turbo Commander 690A?

A. No.

Q. And during today's deposition if I refer to the aircraft or the 690A, you understand I'm referring to the Turbo Commander 690A that was involved in the May 31st, 2011, incident?

A. Yes.

Q. Are you a licensed pilot?

A. Yes.

Q. And about how many years approximately have you had that license?

A. Since about 1990 -- '91.

Q. And what license do you have?

A. It's a commercial license. It's airplane single, multiengine land with instruments, commercial.

Q. And do you fly regularly?

A. Yes.

Q. Do you own a plane?

A. Personally, no.

Q. Do you fly commercially -- let me rephrase that. I bet you do. Do you ever pilot commercially or professionally?

A. No.

Q. Have you ever?

A. No.

Q. What type ratings do you hold?
A. Commercial pilot and also AMP mechanic.
Q. Are you type rated on any particular aircraft?
A. I don't -- I don't think that type rating would apply but I've been signed off to fly various other kinds of aircraft.
Q. What kind of aircraft are you signed off to fly?
A. I've been signed off to heavy fighters such as the P51 Mustang, a North American Heart T6, Folke Wolf 190 A8.
Q. And did you learn to fly those airplanes in military?
A. No.
Q. Did you serve in the military?
A. No.
Q. These are airplanes that you've learned to fly on your own as a hobby or an interest?
A. No, it's usually for a business purpose of some sort because we have aviation interest. But on your own that means no instructor there and, in fact, there are

instructors there --

Q. I'm relieved to hear it.

A. -- and they are needed also.

Q. And I think I asked you this earlier but have you ever piloted a Turbo Commander?

A. No.

Q. Have you ever flown on one?

A. No.

Q. Have you ever inspected one?

A. I've looked them over, yes. And the word "inspection" requires a definition.

Q. Okay. Have you ever personally set foot on board a Turbo Commander 690A?

A. Yes.

Q. How many times?

A. Excuse me. A Turbo Commander, I don't know which model it was.

Q. Okay. How many times have you done that do you think?

A. Oh, once or twice.

Q. In connection with this case?

A. Once, yes; the other time, no.

Q. Tell me about the time you set foot on a Turbo Commander in connection with this case?

A. We got in the cabin, looked around, saw what the clearances were and also looked at it's ACM machine, which was not a Fairchild.

Q. Whose airplane was that?

A. I don't know.

Q. Where did this inspection take place?

A. Baton Rouge Airport.

Q. Who arranged that?

A. A mechanic who runs the Part 145 operation at our airport facility, Mr. Palm.

Q. I'm sorry. What was his name?

A. Palm.

Q. P-A-L-M?

A. Yes.

Q. Approximately how long did that inspection or event last?

A. Oh, 15 minutes.

Q. Were you accompanied by anybody during that inspection?

A. Just Mr. Palm.

Q. Did you take any pictures?

A. No, sir.

Q. Did you make any video or other recording of that event?

A. No.
Q. You said that the ACM on that aircraft was not manufactured by Fairchild; is that correct?
A. Correct.
Q. Who manufactured the ACM on that aircraft?
A. I don't recall.
Q. Did you remove the ACM from the aircraft?
A. This one you're speaking of now, no.
Q. Apart from the ACM on this Turbo Commander that you inspected at Baton Rouge airport, did you examine any other components on the aircraft?
A. No.
Q. I think you mentioned earlier that you also hold an AMP license; is that right?
A. Correct.
Q. And when did you obtain that license?
A. I'd have to look up -- about mid 1990s sometime.
Q. Have you ever worked as a professional aircraft mechanic?

A. I'll have to say, yes, I have. It's not by any profession, it was something I just enjoyed doing.

Q. And did you do that in a professional capacity?

A. Yes, I did.

Q. For approximately how many years?

A. Oh, it's been small things over the years, so I don't know the exact elapsed time.

Q. And when I say a professional capacity, I mean you were paid for the work that you performed on the aircraft. Is that what you mean?

A. Yes.

Q. And what types of aircraft have you serviced as a professional aircraft mechanic?

A. For a period of about more than ten years, a Focke Wolf 190A-8, a Beech Bonanza C35, North American Harvard T6D.

Q. Did any of that work involve maintaining or repairing the environmental control systems on those aircraft?

A. No.

Q. Have you in your work as an aircraft mechanic ever had cause to repair the

environmental control systems on any aircraft?
A. That requires a definition of environmental control system. If you mean those, as indicated, in this particular case, like that, the answer's no.
Q. Do you have an opinion in this case regarding the source of the fumes that were involved in the May 31st, 2011, fume event reported by the plaintiffs?
A. Yes.
Q. And what is that opinion?
A. The opinion is that the visible fume events came from the ACM unit itself.
Q. When you say that it came from the ACM, do you mean that the ACM was the original source of the contaminants that made up the fume event?
A. No.
Q. Tell me what you mean.
A. I mean by that that the ACM let loose some oil, which has a TCM -- TCP isomer in it that got into the cabin.
MR. ODELL:
Did you catch that?
THE COURT REPORTER:

TCP.

MR. ODELL:

Had TCP in it.

BY MR. ODELL:

Q. Is it your opinion in this case that the ACM was a contributing source of the oil involved in the fume event?

A. And contributing source means what?

Q. Did any of the oil that you say was involved in the fume event on May 31st, 2011, originate inside the ACM as distinct from some other component on the aircraft?

A. Originated in the ACM? Most of it I would say the answer would be yes.

Q. Okay. You say most of it. Where did the other oil come from?

A. A slight amount comes from bleed air from the engines.

Q. So it's your opinion, in this case, that the fume event on May 31st, 2011, that forms the basis of this lawsuit consisted of oil contamination in the cockpit; is that correct?

MR. PALMINTIER:

Object to form. You can answer.

I'll do that from time to time.

A. I didn't know what he said. Say that again.

BY MR. ODELL:

Q. Let me try again. It's your opinion in this case that the fume event that was observed by the plaintiffs on May 31st, 2011 --

A. Uh-huh.

Q. -- consisted of oil -- oil in the cockpit; is that correct?

MR. PALMINTIER:

Object to form.

A. There were oil fumes in the cockpit, yes. And that was oil that -- turbine engine oil that has the TCP within it in and got into the cockpit, yes.

Q. And was there any other component to the fumes, in your opinion, other than engine oil?

A. I think, by and large, most all of it would be engine. It might be some other things, I don't know what they might be.

Q. And is it also your opinion that the majority of the engine oil that comprised the fume event came from -- originated in the ACM on the aircraft?

A. The term originated in is a little problematic.

Q. Let me re-ask it then. The ACM on the aircraft has an independent oil supply, correct?

A. It does.

Q. And is it your opinion that that independent oil supply on the ACM contributed oil to the fume event on May 31st, 2011?

A. Yes.

Q. But as I understand it, it is also your opinion that there was oil from another source, namely the engines, that also contributed to the fume event?

A. There's a very slight amount, yes.

Q. And what proportion of the oil involved in the May 31st, 2011, fume event came from the ACM?

A. Most all of it.

Q. Okay. Are you able to be more precise than most all?

A. In my report I did some calculations, which I have available to you, that show the amounts, numbers of drops, and they turn into a cloud. I discussed all that in the

reports.

(EXHIBIT NO. 1 IS MARKED.)

BY MR. ODELL:

Q. Okay. I'm going to hand you what's marked as Exhibit 1 to your deposition. Take a look at that and tell me if this is a copy of the report that you prepared in the case?

A. It is.

Q. And is this the report that you made reference to in your answer just now?

A. Yes.

Q. Okay. And why don't you direct me to the calculations you performed that will show us the proportion of engine oil that originated in the oil supply of the ACM?

A. Well, my answer earlier was that it was most all of it, and that in numbers of drops in the -- excuse me -- Exhibit A, we show that there are super critical number of drops. And the only place that can come from is the ACM. One thing I didn't say in here, but was hoping the other experts would pick up on it, is that there's only a slight proportion comes from the engine. That's the number of 6 divided by 1,000. So in that proportion, I would say, would form my

answer that most all of it came from the ACM.

Q. Okay. And so you've directed us to Exhibit A, to Exhibit 1, which is shown on page 11 of 18 in Exhibit 1; is that correct?

A. That's our calculation on numbers of drops.

Q. And please direct me to the calculation in Exhibit A of Exhibit 1 that shows the proportion of engine oil that came from the ACM's independent oil supply.

A. It's not there. It was done in my head. And I referred to it, it's over in other parts of the report itself, that only a small portion would basically come from the engine. I did make the exact statement it came from the ACM.

The only thing that could be noticed, and I'll go back to Exhibit A -- let's see. In here where I discussed a visible fume event, how many drops that would take is way more than could possibly come from the engine.

Q. Okay. Why don't you show me where you're referring in you report?

A. Okay. I'll have to sit back and read it to find it. All right. It's on page 4

of 18 under the discussion. And it says several sentences down, we refer to OSHA standards, and then the EH 40 standard. And then we point out that in order to see a vaporized event, you had to have five-tenths milligram per cubic meter. We give a reference to that to see it.

Q. Show me where it says that to see a fume event, you would need five-tenths milligram per cubic meter. I'm looking at the bottom of page 4 of 18 in Exhibit 1. I'm not seeing that.

A. Well, it's in the sentence up there. "The estimated ToCP concentration in a cabin during a fume event in which aerosol vapor or vaporized liquid can be seen is .5 milligrams per cubic meter." And we gave a reference.

Q. Okay. And how does this tell us that the oil involved -- if there was oil involved in the May 31st, 2011, fume event had to have come from the ACM as opposed to the engine?

A. Because the engine can't put out that much oil.

Q. How much oil does the engine -- strike that. How many engines are there on a Turbo Commander 690A

A. Two.

Q. And how much oil does each engine contain?

A. I don't know how much they contain.

Q. Is it more or less oil than is contained on a Fairchild BUR-20 ACM?

A. Oh, far more oil.

Q. But despite the fact that the engine contained far more oil than does the Fairchild BUR-20 ACM, it's your contention that the engines could not have supplied as much oil into the bleed air as the ACM did?

A. No. That's got nothing to do with it, that analogy you just painted. It's actually how many drops per minute can each engine leak into the airstream? And that was given -- it's referred to in our report also, is 15 drops per minute from Garrett engines themselves. It's a static rate, but it's the only data I have at this time.

Q. And is that the leakage of oil under normal operating conditions for a Garrett engine?

A. No. I said it was static conditions. That's the only data I have at this time.

Q. In the event of a malfunction with

the engine, is it possible that the engine could leak more than 15 drops per minute?
A. What would be that malfunction?
Q. I don't know. Are there any malfunctions, that you're aware of, that could cause an engine to leak more oil than 15 drops per minute, did you say?
A. I think that was the number that Garrett gave us, yes. Possibly some seal could give up. But then you see a lot of smoke coming off the exhaust as well. So it would be quite obvious. And I think no one saw any evidence of that. They checked for that. So the 15 drops a minute is the data I had at this time.
Q. Okay. But it is possible, though, that if there were malfunction on the aircraft, such as a cracked or defective seal on one of the engines, that it could leak more than 15 drops of oil per minute --
MR. PALMINTIER:
Object to the form.
BY MR. ODELL:
Q. -- correct?
A. It would depend upon the conditions of what you're saying. I have no knowledge of

that right now.

Q. You have not inspected the engines on the aircraft involved in the May 31st, 2011, incident, correct?

A. I have not.

Q. Have you ever serviced Garrett aircraft engines?

A. No.

Q. Have you spoken with anyone at Garrett to determine whether these engines have a history of oil leakages that could allow them to introduce more than 15 drops of engine oil per minute into the bleed air?

A. No.

Q. Have you reviewed the maintenance records for the aircraft involved in the May 31st, 2011, incident?

A. Those that were made available to me, yes.

Q. Did the maintenance records that you reviewed contain any indication of oil leakages within the engines on the aircraft?

A. No. The ones that I reviewed and testimony shows that they didn't find any.

Q. You did not see any references to an

oil leak or evidence of an oil leak from the engine from the aircraft; is that right?
A. I don't recall seeing any data.
Q. This report now is dated January 14th, 2016. Is that the date that you finalized the report?
A. I think so.
Q. Have you done any work on this case since January 14, 2016, other than appearing for your deposition today?
A. Yes. We looked up some things on the internet, patents, things like that. That's all.
Q. I'm sorry, I didn't quite catch that. What did you look up the internet?
A. We looked up some data on the internet about patents that the Fairchild has, just various things like that. That's all.
Q. What sort of patents were you looking up?
A. Well, we looked up one patent that has Mr. Dziorny's name on it that shows that they could have a design for bearings on the outside that were greased and not oiled. And that we found, I think, the original patent for the

BUR-20 unit.

Let's see. We found that original patent. We found a few more of them and just reviewed them on the internet, basically.

Q. Other than your internet review and research of patents held by Fairchild, have you done any other work since January 14, 2016?

A. I don't recall any sitting here today.

Q. Have you reviewed any additional case materials, such as expert reports in this case since January 14th?

A. No.

Q. You made reference to Mr. Dziorny?

A. Yes.

Q. Is that Paul Dziorny?

A. I believe so.

Q. And he's an employee of Fairchild Controls Corporation; is that your understanding?

A. I think so.

Q. Did you review the report or declarations prepared by Mr. Dziorny in this case?

A. I did.

Q. He's prepared both a declaration and

a report. Did you review both of them?
A. No, just the one declaration report is all I saw.
Q. Have you been asked to prepare any kind of a response or rebuttal to that?
A. I have not.
MR. PALMINTIER:
For the record, since you asked about whether he's been asked, that would be from me. And we do reserve the right to ask him to look at it. But, of course, it's only been a couple of weeks that we've had the reports. So we reserve that right.
BY MR. ODELL:
Q. When were you first retained in this case, Mr. Hansen?
A. In 2014 sometime. I don't remember the month.
Q. Who retained you?
A. Mr. Palmintier.
Q. Did you begin actively working on the case at that time?
A. Yes.
Q. How are you being compensated for

your work in this case?

A. Nicely.

Q. I'm happy to hear it. Are you on a retainer with Mr. Palmintier's firm?

A. No, we're paid hourly.

Q. And how many hours, approximately, have you got on the case so far?

A. Have no idea.

Q. More than 100?

A. Oh, I'm sure. I just don't know sitting here today.

Q. What is your rate in this case?

A. I believe it's the same as what's quoted to you. It's 275 an hour, if I'm not mistaken.

Q. Is that your standard rate for expert work of this type?

A. It is.

Q. Approximately what proportion of your practice today is devoted to serving as an expert witness?

A. Today, I have no idea. A small percentage.

Q. Over the past year, what would you say?

A. Much more. You want to go ahead and get a good answer, I think we looked it up. I mean, over about the last decade or so, it's been roughly 30 percent. Sometimes more, sometimes less.

Q. When Mr. Palmintier first retained you in this case, what did he ask you to do?

A. To --

MR. PALMINTIER:

Form. I'm going to let him answer generally. But I'm not going to allow you to ask him what I specifically -- anything from my mental processes.

MR. ODELL:

Please don't tell me Mr. Palmintier's mental processes, to the extent you understand them. I'll discover those on my own.

MR. PALMINTIER:

Thank you.

BY MR. ODELL:

Q. What were you asked to do in performing your expert services on this case?

A. Asked to render mechanical engineering opinion on the ACM, having to do with

this oil event, fume event.

Q. And were you asked to evaluate any other components on the aircraft?

A. No.

Q. Have you performed that work on your own in this case or have you had the assistance of others at your firm?

A. Yes, assistance of others.

Q. Who else at your firm has worked with you in preparing your opinions in this case?

A. Numerous people. Mr. Blanchard, Dr. Mount, Mr. Fudge, Mr. Landon, and two or three others. I just don't remember.

Q. Going back to what you said earlier about the Garrett engines having a static discharge of I think it was 15 drops of oil per minute; is that correct?

A. Yes.

Q. Is that per engine or combined?

A. That's per engine.

Q. So that would be 30 drops of oil per minute?

A. For the -- possibly.

Q. If both engine were operating at that time, it could be as much as 30 drops of oil

per minute under normal operating conditions; is that right?

A. No, it is not right.

Q. What's wrong about that?

A. What's wrong is the word operating. I said static conditions, meaning it's not running, it's just probably a test number.

Q. Okay.

A. And during running conditions it may leak way less. I just don't know, sitting here today.

Q. Could it leak more?

A. I doubt it --

Q. Why?

A. -- I really do.

Q. Why?

A. Well, just from knowing engine design like that, usually the static leak check is the worst thing.

Q. But, again, you've never serviced a Garrett engine, correct?

A. That's correct.

Q. You don't have any personal familiarity with their servicing or their problems or whatever oil leakage issues Garrett

engines, in particular, may have; is that correct?

A. Not other than documents I have from them in this case.

Q. So, going back to my original question. The static combined oil leakage of both engines on a Turbo Commander would be 30 drops of oil per minute; is that correct?

A. Static, yes.

Q. And how many drops of oil per minute do you believe would have been involved in the May 31st, 2011, fume incident?

A. We said that in our report in order to see it, we -- it's a number, I just read it to you earlier, I've lost it again here. But it looks like a number of roughly 5 milligrams per cubic -- a .5 milligrams per cubic meter.

Q. .5 milligrams per cubic meter --

A. Right.

Q. -- is the contamination of the cabin in order for it to be visible, correct?

A. Right.

Q. So do you have an opinion about how many drops of oil in the air system would be required to yield a visible haze of that

concentration?

A. Yes. It's in the report. We talked about, in fact, I'll refer you to Appendix A, critical drops per minute, hour, or whatever. It doesn't matter too much.

Q. And how many drops of oil is that?

A. Well, we'd have to go look -- I'll refer you to Appendix A again. It's at the bottom of the page, super critical drops of oil are 3.2415 drops.

Q. You're looking at the sentence at the bottom of page 11 of 18 in Exhibit 1; is that correct?

A. Near -- near the bottom, yes.

Q. Let me read it out loud and make sure I've got the right -- I see. There's a calculation says, "Super critical drops of oil equals 1.0805 drops times 3 equals 3.2415 drops"; is that correct?

A. That's right.

Q. Is that per minute?

A. The units don't minuter too much. That's however many drops would be in the cabin in any time interval.

Q. Okay. And the -- and each engine,

as we know, loses approximately 15 drops of oil per minute under static conditions?

A. If I remember the number correctly from the data, I think it's 15 per minute.

Q. And it's your belief, although you can't point me to any documents in the record, that during operating conditions, the engines would lose less oil than 15 drops per minute, correct?

A. I cannot point to anything but 15 drops. That's all the data I have available to me at this time.

Q. But despite that, it's your opinion in this case that the two engines combined, under operating conditions could not have produced 3.2415 drops sufficient to cause a haze in the cabin as observed by the pilots; is that right?

A. No. The question is a little convoluted there.

Q. Okay.

A. You have to realize, and I've already explained this, say the 30 drops a minute from both engines, only a tiny fraction can get into the cabin, a very tiny fraction.

So the 15 drops is just what the

gross engine produces. Most of that is combusted, I should imagine. Very little bit comes out the side stream, they call it bleed air. It's an extraction point on a compressor. And only a tiny amount of that is able to go through the ACM, and through the bypass and get into the cabin at all.

So the proportion, as I said earlier, is a number of roughly 6 divided by 1,000. So it's a tiny, tiny amount. And the engine can't put out that much; therefore, the rest of it came from the ACM.

Q. The 6 of 1,000 proportion that you referenced, that is the proportion of oil leaking from the engines that makes it into the bleed air?

A. Yeah, that's all that can get in there.

Q. And what's the source for that data point?

A. Knowing what the -- it's fairly common knowledge -- of how many pounds mass per second each of these 311 engines -- 331 engines produce. It's a full power, I believe, I saw it's 8 pounds mass minutes per second of air is

compressed. So at some lesser flight power setting, say 75 percent power might be the number 6 times 2.

Q. Prior to this case, have you ever given testimony in expert witness capacity in any lawsuit involving cabin air contamination issues?

A. No.

Q. Have you ever been qualified as an expert witness in any court proceeding other than this one with regards to an Air Cycle Machine?

A. No.

Q. Have you ever served -- have you ever been qualified as an expert in any other court proceeding involving an aircraft or aviation issues?

A. Yes.

Q. Okay. How many?

A. One very large one.

Q. And what was that?

A. It's in the -- Anofils vs. General Motors.

Q. You were referring to the list of legal and forensic cases contained in your expert report?

A. It would be there also. But in the

resumé, the curriculum vitae, itself, I believe that one's called that.

Q. Tell me the name of that case again.

A. Anofils vs. General Motors.

Q. And what was the nature of that case?

A. It was wrongful death, having to do with failure of turbo prop engine on a commuter airplane.

MR. PALMINTIER:

Can you give me two minutes, just need a very short break?

MR. ODELL:

Sure, go off the record.

(Short break)

BY MR. ODELL:

Q. Before we broke, Mr. Hansen, you were telling me about the Anofils case in which you served as an expert. And I think you described it as a wrongful death case involving a commuter flight; is that correct?

A. That's right.

Q. Did you work for the plaintiff in that case?

A. Yes.

Q. And did you testify or did you -- strike that. Did that case go to trial?
A. No.
Q. Did you prepare a report in that case?
A. Yes.
Q. Did you give a deposition?
A. Oh, yes.
Q. More than one?
A. Ten days.
Q. You were in the hot seat for ten days?
A. Yes.
Q. We'll try to cut this one a little bit shorter. No promises though. Did that case involve any allegations of a malfunction of the ACM?
A. No.
Q. I think you mentioned that it had to do with engine issues?
A. Yes.
Q. Were there any other components involved in that?
A. Well, the engine and prop reduction gear box were the only two components.

Q. And you testified about alleged defects in those components; is that correct?
A. Yes, I did.
Q. Was there a motion to disqualify you or exclude your testimony in that case?
A. Yes.
Q. And did that motion succeed?
A. No.
Q. But it did not go to trial, correct?
A. That's right.
Q. Other than the Anofils -- strike that. Other the Anofils case and the one we're here on today, have you ever testified as an expert in any other aviation-related cases?
A. No.
Q. You testified earlier today that in your one time on a Turbo Commander, you looked at the ACM and saw that it was not manufactured by Fairchild; is that correct?
A. That's right.
Q. But you don't recall who manufactured that ACM?
A. I do not.
Q. Is it your understanding that the ACM installed on the 690A involved in the May

31st, 2011, incident was manufactured by Fairchild?

A. Yes.

Q. And what is the basis of that understanding?

A. Records given to me in this case.

Q. Which records?

A. Those that are on a disk that you'll be handed later today, all the case documents.

Q. Okay. And you have a hard copy of your case -- of the case documents you're referring to with you today?

A. The case documents means everything, including the complaints, all this?

Q. Well, let me ask the question a little more specifically.

Do you have a copy of the document you're referring to that identifies Fairchild as the manufacturer of the ACM installed on the aircraft involved in the May 31st, 2011, incident?

A. I do.

Q. Okay. Can you show that to me?

A. Sure. There's several place it is. The reports is the --

MR. PALMINTIER:
Just answer the question.
THE WITNESS:
He wants me to show it to him?
MR. PALMINTIER:
Uh-huh (affirmative).
BY MR. ODELL:
Q. Okay. And for the record, you've shown me the expert report of Paul Dziorny and a report prepared for the defendants by Matthews Lykins; is that correct??
A. Correct.
Q. And you're relying on these documents for your contention that the ACM on the May 31st, 2011, incident aircraft was manufactured by Fairchild?
A. Yes.
Q. And both of these documents, I note, are dated after the date of your report. When you prepared your report, did you have any idea whether a Fairchild ACM had been on the aircraft?
A. I did.
Q. And what were you relying on for that understanding when you prepared your report?
A. The background information and

complaints, Kenneth Davidson deposition, Dr. -- Thomas Farmer deposition, Dr. Harrison deposition, Mr. Probst's deposition, Van Netten deposition, and Fairchild documents and manuals that were given to us in this case by Mr. Palmintier.

Q. Okay. And all of those documents that you've referenced positively identify the manufacturer of the ACM on the May 31st, 2011, flight as Fairchild; is that correct?

A. That is my belief, yes.

Q. Have you personally inspected the ACM that was on the aircraft during the May 31st, 2011, event?

A. No.

Q. Have you spoken with anybody who has personally inspected that ACM?

A. No.

Q. Have you seen photographs of the ACM that was involved in the May 31st, 2011, flight?

A. No.

Q. Have you personally inspected any Fairchild ACM models BUR-20?

A. Yes.

Q. When -- tell me about that. Is it

just once?

A. We have one exemplar at this time.

Q. And you say we, is that your firm?

A. Yes, we bought one.

Q. And where did you obtain that ACM?

A. I don't recall the name of the vendor we received it from.

Q. When did you obtain it, do you recall?

A. Some months ago.

Q. But to your knowledge, the ACM that your firm bought is not the one that was involved in the May 31st, 2011, flight?

A. That's correct.

Q. If you turn to Exhibit 1, which is your report in this case, there's a picture listed as figure 1 on page 3. Is that a photograph of the ACM that your firm bought?

A. It is.

Q. Do you know when that ACM was manufactured?

A. I do not.

Q. But it's your understanding that this is a BUR-20 ACM?

A. It is.

Q. Do you know the serial number of the ACM that was installed on the 690A on May 31st, 2011?

A. It's on the data tag, which is in the picture, but I can't read it.

Q. You're referring to the picture -- is it --

A. Yes, you'd have to expand it.

Q. Let me re-ask the question. Do you know the serial number of the ACM that was installed on the aircraft involved in the May 31st, 2011, incident?

A. I don't believe I do.

Q. Okay. The picture that appears in figure 1 in your report is not a photograph of that ACM, the one involved in the May 31st, 2011, incident, correct?

A. That's right. This is our exemplar, as indicated on the picture.

Q. Do you know when the ACM that was installed on the 690A aircraft on May 31st, 2011, was manufactured?

A. I do not.

Q. Do you know whether that ACM had been overhauled or repaired prior to installation

on the 690A?

A. I believe it had.

Q. Do you know how many times?

A. I do not. It may be in the deposition, but I don't recall.

Q. Do you know who installed the ACM on the 690A, the one that was involved in the incident?

A. The person?

Q. Or the entity?

A. I don't recall.

Q. Do you know what procedures were followed in installing that ACM on the incident aircraft?

A. Well, you use the word know, which means I would actually have seen it or had the papers in front of me. I do not.

Q. So you don't know whether -- whoever installed the ACM on the incident aircraft followed Fairchild's procedures for doing so; is that right?

A. I have no knowledge.

Q. Do you have any knowledge whether the ACM involved in the May 31st, 2011, incident had been properly maintained by the operator of

the aircraft prior to May 31st?

A. I don't know.

Q. If you turn to page 5 of 18 of your report, I call your attention to -- well, before I ask you that, let me ask you: Who authored this report?

A. I did.

Q. Are all of the statements and opinions contained in this report yours?

A. Yes.

Q. And is there anybody else that -- at your firm who would be a better source for us to speak to about the opinions contained in this report than yourself?

A. I'll say no.

Q. If you turn to the sixth paragraph on page 5 of 18, the one that begins with the word "additionally." You see that?

A. Yes.

Q. It says, "Additionally, there's no way for a pilot or aviation mechanic to determine the effectiveness or operating state of the hidden ACM's oil seals." Why do you refer to it as hidden?

A. Because they're inside the unit.

Q. When you toured a six -- a Turbo Commander at the Baton Rouge airport, you were able to get into it and see it; is that correct?

A. No, I didn't say that.

Q. So you did not see the ACM that was installed on the aircraft during your inspection?

A. I saw an ACM, it was not a Fairchild ACM.

Q. Okay. If it was hidden, how were you able to see it?

A. Well, I didn't say that that one we looked at that day was hidden. I'm referring to this. By looking at our exemplar, you can't tell from the outside that a seal is leaking can like you can with an engine, for example, is what I mean by this.

Q. So it's the oil seals that are --

A. Yes.

Q. -- hidden, in your words, not the ACM itself?

A. Oh, yes, that's right.

Q. Okay. That was the source of my misunderstanding. I appreciate that. You go on to say, "The only way to determine the effectiveness of these important items is to send

the ACM in for overhaul by Fairchild, a process that nearly guarantees a fume event. Both the original ACM and the overhauled ACM had evidence of oil leakage from the turbine side and the impeller side of the rotor, thus indicating ACM oil seal leakage."

And my question for you is, what is the factual basis for your contention that the original ACM had evidence of oil leakage from the turbine side and the impeller side of the rotor, thus indicating ACM oil leakage?

A. Deposition testimony.

Q. And whose deposition?

A. It was the pilot's and also Probst, I believe.

Q. So that would be Mr. Farmer; is that right?

A. Farmer. Farmer and --

Q. And Mr. Probst?

A. -- Probst.

Q. And did you attach -- I noticed that attached to your report are some deposition excerpts, correct?

A. Yes.

Q. And did you attach the pages that

you're relying on for that statement?

A. Oh, probably one of them. I don't remember.

Q. Take a look for us and see if you can direct me to that passage. And I might be able to expedite things. If you look at attachment PAI-8 to your report.

A. That's what I'm looking for. I just -- I wasn't seeing it so quickly in there. Let's see if I can find it here. Here it is.

Q. You got it?

A. Right. Uh-huh (affirmative).

Q. And this is an expert from the September 5th, 2012, deposition of John Probst, correct?

A. Correct.

Q. You understand that was taken in a different proceeding than the one that we're here on today?

A. I don't know.

Q. Okay. I'll represent to you that as the style at the top of the Probst deposition excerpt shows that's from a workers' compensation proceeding titled Kenneth Davidson, Jr., versus Chartis Claims Northrop Grumman. Do you see that

at the tope of PAI-8?

A. Yes.

Q. So now that we've got this in front of us, direct me, if you would, to the passage in Mr. Probst's deposition that indicates that there was evidence of oil leakage from the turbine side and the impeller side of the original ACM; that is, the ACM that was installed on the aircraft of May 31st, 2011.

A. That's found on page 166 and 167.

Q. Okay.

A. And 168. It's basically a lot of this page.

Q. So page 166, as you see at the top of that page, refers to a maintenance log for the serial number 335 machine, correct?

A. Yes.

Q. And is it your understanding that the machine bearing serial number 335 was installed on the aircraft on May 31st, 2011?

A. No, it was installed later.

Q. Okay. And in the middle of the page 166, Mr. Probst answered some questions about the cause of the failure of the 335 ACM, correct?

A. Yes. Yes, he does.

Q. And there's the phrase -- question is: "There is evidence of oil leakage from both the turbine side and the impeller side of the rotor," correct?

A. Yes.

Q. But that is specifically referring to the 335 machine, which was put into the aircraft after May 31st, 2011, correct?

A. That particular sentence says that, yes.

Q. Okay. And at the top of page 167, the question is posed to Mr. Probst: "So consistent with that, doesn't it make sense that there would have been oil leakage from both the turbine side and propellor side of the rotor in the original ACM that was in the aircraft on May 31st, 2011," correct?

A. It says that. But you took some things out of context and failed to mention some other lines of testimony in here. And that would be basically lines 166, 12 through 25. And then you ignored completely lines 1 and 2 at the top of page 167.

MR. PALMINTIER:

I'm shocked.

BY MR. ODELL:

Q. Okay. And --

A. Only including, I think, line 3 through 9, I think it was. But then if you take 10 on further down, you find some different things.

Q. Well, let's look at the passage that you've referenced. So at line 23 of page 166, the question is posed to Mr. Probst: "So the problem that this 335 machine had, would you agree, was the same problem that your original machine had"? And Mr. Probst's answer was: "I would venture to guess it's the same problem they all have when they go in to be repaired," correct?

A. It says that.

Q. And so --

MR. PALMINTIER:

Are you asking whether you read it correctly or is that the question?

BY MR. ODELL:

Q. Did I read it correctly?

A. I think you did, yes.

Q. And is that one of the passages that I had earlier omitted --

A. Yes.
Q. -- to read to you?
A. Yes, it is.
Q. And you think this is important, correct?
A. Well, sure.
Q. Why is that?
A. Well, the important part is that they all seem to have bleed pass rubs, which is a high vibratory condition, which can cause a leak of oil, in my professional opinion. And this 335 machine, the new one, which also had fume events, exhibited a similar to before. And he's asked Probst up in lines 1 and 2 what he would say that he guessed that it's the same problem they all have to be repaired.
Q. And Mr. Probst is guessing here, to use his words, right?
A. But that's not a bad guess, probably a good statement.
Q. Okay. So in reaching your professional opinion in this case, are you relying on Mr. Probst's guess?
A. Not entirely.
MR. PALMINTIER:

Object to the form.

BY MR. ODELL:

Q. You're relying to some extent on his guess, though, correct?

A. His testimony.

MR. PALMINTIER:

Object to the form.

BY MR. ODELL:

Q. And so then the portion that I read to you, and we can read it again, if it's helpful, the question I asked Mr. Probst if it makes sense, that there would have been oil leakage from both the turbine side and the propeller side of the rotor in the original ACM that was in the aircraft on May 31st, 2011, correct? Did I read that correctly?

A. Yes, you did.

MR. PALMINTIER:

Well, you understand the reason why I'm asking for the distinction is --

BY MR. ODELL:

Q. What was Mr. Probst's answer?

A. If there were any evident of it, yes -- evidence of it, yes. But there was no evidence of it anywhere.

Q. It was Mr. Probst's testimony that there was no evidence of oil leakage from the turbine side and the propeller side of the rotor in the original ACM that was in the aircraft on May 31st, 2011, right?

A. That's what he said.

Q. Okay.

A. But you'd have to understand what he means by evidence, that it was visual. You probably couldn't see it because of the amount of oil required to make a cloud, a fume event in a cabin is so tiny.

Q. So not -- so are we to understand, then, that you have a better understanding of what Mr. Probst meant than what's reflected in his deposition transcript?

MR. PALMINTIER:

Object to the form.

A. Possible.

BY MR. ODELL:

Q. And so when he says there is no evidence of oil leakage, you think he actually meant that there was evidence of oil leakage; is that right?

A. No, I said he didn't see it. I

believe that it's a visual inspection or a visual look. And that's what he's referring to, that's my belief.

Q. Okay. And so you assign weight to his guess --

A. Uh-huh (affirmative).

Q. -- as to what happened to the original ACM installed on the aircraft, but no weight to his visual inspection of the ACM itself; is that right?

MR. PALMINTIER:

Object to the form. Argumentative and misstates previous testimony.

BY MR. ODELL:

Q. You can answer the question.

A. I already stated why. Because the amount of oil would probably not be seen by him because it's such a small amount required to cause a fume event.

MR. ODELL:

Can we either go on a break or have a side bar on the record because it's a little confusing to have the witness and counsel for the plaintiffs whispering to each other during the deposition?

MR. PALMINTIER:
That's an absurd objection.
MR. ODELL:
I'm afraid it's not all getting --
MR. PALMINTIER:
We're hearing what you're saying.
MR. ODELL:
I'm afraid it's not being captured on the record.
MR. PALMINTIER:
You can record it, Madam Reporter. I asked him where he was looking in the documents. Don't be ridiculous, Chris.
MR. ODELL:
All I could tell is that you're whispering with the expert --
MR. PALMINTIER:
Play your game somewhere else.
You're in my office now.
MR. ODELL:
-- and I'm just asking that if you're --
MR. PALMINTIER:
Want to call the judge?
MR. ODELL:

-- you're going to communicate with the expert --

MR. PALMINTIER:

Let's call the judge and see whether I can't ask what page the witness is looking at.

MR. ODELL:

All I'm asking -- Mike, why don't you have a seat and stop having a tantrum. I asked that you --

MR. PALMINTIER:

This is on the record?

COURT REPORTER:

I'm typing it.

MR. ODELL:

-- carry on your sidebar communication with the expert --

MR. PALMINTIER:

Did he just accuse me of having a tantrum on the record?

MR. ODELL:

Why don't you have a seat, Mike?

MR. PALMINTIER:

Because I'm getting up to get some coffee, Chris.

MR. ODELL:

Okay.

MR. PALMINTIER:

Can I get anybody anything? I think I may have drunk some of your water. I'm not contagious. You can proceed. Go ahead. I was asking -- I'll ask you. What page of the report were you looking at?

MR. ODELL:

It's PAI8.

MR. PALMINTIER:

PAI8.

BY MR. ODELL:

Q. Are you aware of any evidence that the ACM installed on the aircraft on May 31st, 2011, showed evidence of oil leakage from the turbine side and the impeller side immediately after that event?

A. My understanding is that from deposition testimony, that whenever it was disassembled, I assume at the Fairchild shop, that they had noticed some of this.

Q. And you understand that was not immediately after the May 31st incident, correct?

A. I don't know when it was.
Q. Was it more than a month later, do you know?
A. I really don't recall that. I'm sure it must be in here. I just don't recall.
Q. You don't know whether it was more than three months later?
A. I don't recall.
Q. Do you know how many hours the aircraft operated with that ACM in it between May 31st and the time that it was inspected by Fairchild?
A. I believe I've seen 50 or 55 hours, something along those lines.
Q. And so if there were any defects or cracks or leaks or busted seals in the ACM that were discovered when it was ultimately inspected by Fairchild, it could have happened at any time during that 50-odd hours of operation, correct?
MR. PALMINTIER:
Object to the form.
A. What could have happened?
BY MR. ODELL:
Q. The crack or leak in the seal.
MR. PALMINTIER:

Same objection.

A. Not necessarily. Cracks and leaks aren't necessarily the issue here. It could be a vibratory offense, too, that could cause the seal to become ineffective or some other part to become ineffective.

Q. And that could have occurred sometimes during the 50 hours of operation, approximately, between May 31st and whenever it was removed from the aircraft, correct?

A. It might have.

Q. Do you know how long a Fairchild BUR-20 ACM can continue to function after it starts to leak oil?

A. Well, probably a long time. When it starts to leak, you're having to find that. But I'll say if it's something wrong with it, the seals, per chance, may be vibratory events, it happened just occasionally, I believe it could happen and it still function.

Q. Is that an educated guess on your part or are you referring to some source or document that we can look at?

A. Basically, my experience as a mechanical engineer for 50 years.

Q. But, again, you've never actually serviced an ACM in connection with your work as an engineer or an aircraft mechanic, correct?
A. Service meaning what?
Q. Ever repaired an ACM, for example?
A. Of course not. A mechanic would not be allowed to repair or even take apart an ACM. If he even removed or loosened a bolt, tightened it back up, and put it back in the airplane, the FAA would be all over him. That's the start of an overhaul. That's a serious infraction.
Q. And you've never been involved in maintaining an ACM on an aircraft, correct?
A. Nobody is. It's Fairchild's job. When you mean maintenance, about the only thing anybody can do is check the oil level, that's it.
Q. And you've never even done that, right?
A. Never even done that.
Q. Apart from the Turbo Commander 690A involved in this lawsuit, are you aware of any other fume events on other aircraft involving the same model of ACM, the BUR-20?
A. Only those referred to in deposition testimony about they have lots of problems with

this, even with other aircraft. That's the only thing I know about it.

Q. Involving a Fairchild BUR-20 ACM?

A. That's my understanding, but I'm not certain about it. I just saw reference to it in depositions.

Q. And this is an important point, so I'm going to be clear about it. It's your understanding that you reviewed a deposition that made reference to fume events on other aircraft involving a Fairchild BUR-20 Air Cycle Machine; is that correct?

A. That's my recollection from what I've read.

Q. Whose deposition?

A. I don't recall.

Q. Okay. You have the depositions with you?

A. I don't recall that either.

Q. Was it a deposition provided to you by plaintiff's counsel in this case?

A. Yes.

Q. But you don't recall whose deposition?

A. The best I can come up with in my

memory is Mr. Farmer, the pilot, and possibly Probst as well. But I'm not certain.

Q. It's your understanding that Mr. Probst and/or Mr. Farmer testified in their depositions that there have been other fume events on other aircraft, not this Turbo Commander 690A, but other aircraft, that involve the same model of ACM at issue here; is that right?

A. That's the impression I got from reading their words.

Q. Okay. Are you able to point us to a specific passage in either gentleman's deposition to support that impression?

A. Oh --

MR. PALMINTIER:

He's not asking you to comb through all your documents.

THE WITNESS:

Well, I would have to do that.

BY MR. ODELL:

Q. Well, you've identified two depositions.

A. Uh-huh (affirmative).

Q. I need to know if one of those

contains the point that you are making because I'm not familiar with it. So you have them in front of you, would you please point us to the passage that you're referring to?

MR. PALMINTIER:

Are we going to shut down for about an hour?

MR. ODELL:

We can go off the record, and Mr. Hansen can take his time --

MR. PALMINTIER:

Take your time. Let's go -- you want us -- we can go in the -- he can go in my office or you can stay in here, whichever you'd like. This is deposition time. You're asking him to review --

MR. ODELL:

No, we're going off the record. It's his contention in this case. If he has no -- if he has no source for it, that's fine. He can just say that. He's told me that he does have backup for it. I've asked what it is. I don't think it's unreasonable to ask him to point me to it.

MR. PALMINTIER:

It is unreasonable for you to ask him to read through hundreds of pages of depositions during the deposition. So -- I mean, you have the prerogative to let him do that, but it's going to be deposition time.

MR. ODELL:

Well, I don't -- I don't agree with that at all, Mr. --

MR. PALMINTIER:

Take your time and look. That's what he wants you to do.

THE WITNESS:

Okay.

MR. ODELL:

If we're going to --

MR. PALMINTIER:

Just when you finish, call me.

THE WITNESS:

Okay.

MR. ODELL:

Let's go off the record.

(Off the record)

BY MR. ODELL:

Q. Mr. Hansen, are you ready?

A. Yes.

Q. So we were off the record for a while, a little over 90 minutes, I think, while you and Mr. Palmintier had a chance to review some of the depositions in this case. Were you able to find the citations you referenced?

A. Yes.

MR. PALMINTIER:

Form.

BY MR. ODELL:

Q. And can you direct us and show me what you're referring to?

A. I'll read the references to you.

Q. Whose deposition are you turning to first?

A. Harrison, M.D.

Q. That's Mr. Harrison's -- or Dr. Harrison's deposition taken in a workers' compensation proceeding, I think?

A. I think so, whatever. I don't understand all that. But on these pages 21, 22, 23, and 24, he refers to surveys of flight attendant of symptoms of exposure. And we know that these events occurred more frequently into his reports. We get doctors -- get two doctors

like myself. This tells me that -- indicated to me that in the fleet of aircraft that would have an ACM of anybody's in there, there's apparently some issue with the cabin contamination.

Q. Dr. Harrison doesn't say anything in the passage that you're citing on these pages about Fairchild ACMs, in particular; is that correct?

A. Yeah. He didn't name anybody's. But he says it look to be -- I'm just using some words now, a fleet-wide issue.

Q. Okay. And do you know what aircraft he was referring to?

A. He doesn't say.

Q. Okay. And the next reference?

A. Is him. I think it's page 28. It's -- "that's obviously the whole purpose is to maintain the whole aircraft so you don't have mechanical failures or problems so that you get essentially clean air come in the cabin for passengers and flight crew." And that tells me again, the same thing as before, it's my impression that it's a fleet-wide problem.

Q. And, again, before we leave this, that's page 28 of Dr. Harrison's deposition; is

that right?

A. Yes.

Q. And, again, in that passage, does Dr. Harrison make any reference to Fairchild ACMs or other Fairchild components by name?

A. He does not. But it references the fleet, and 690s are within the fleet.

Q. But before we leave that, does he say anything about Twin or Turbo Commanders, specifically?

A. No.

Q. And the next reference?

A. Is again his deposition, page 33. "Bleed air refers to air that's routed as it's coming into the engine intake through a system that cools and pressures the air, and then supplies it to the passenger cabin and flight deck. The air that is breathed by passenger and crew on aircraft is brought in from the outside as the aircraft is flying."

And so, again, he talks about air problems and the pressurizing. If there's a mechanical problem, the bleed air, it's in the air runs a risk of becoming contaminated with engine oil that's used to lubricate the engine

itself. So this, again, and to the question can bleed air system play a role in fumes entering the cabin? And the answer is yes.

Q. And on this -- what page was that?

A. 33.

Q. And on page 33, Dr. Harrison is specifically referring to the oil that lubricates the engine and not the ACM; is that correct?

A. In this particular case, it's true.

Q. And he does not reference a Fairchild ACM or other Fairchild components in this passage?

A. Did not reference those. But, again, he's talking about the fleet of aircrafts of which the 690 would be a part of that.

Q. And does he make any specific reference to the Turbo Commander or the 690 in this passage?

A. No, he doesn't. But again, like I just said, normally go with referencing the fleet of aircraft.

Q. You're assuming that by fleet, he is referring to what aircraft?

A. All aircraft that have these issues --

Q. Which issues are those?
A. -- of contamination of the air in the cabin.
Q. Can you give us a list of the aircraft that have these issues?
A. There are -- we'd have to go off the record again. In search, I saw the 737. Some of the larger ones, of course, we have the 690A. And, probably, I think I saw a King Air at one place in here someplace. Someone named several of those. But it wasn't important for me to look into that.
Q. Okay. And the next reference?
A. Is -- this is in -- I think it's still his deposition. And it's page 68 now. He says, "My experience in reviewing all the patients that I've seen from bleed air contamination has led me to conclude there's definitely a number of individuals who have persistent, chronic, or permanent neurologic problems. They last for months. Some cases permanent. It's also consistent with what we know about other toxic chemicals that affect nervous system in the workplace."
So this tells me again that bleed

air or contamination of the cockpit is a fleet-wide issue that this particular doctor had looked into.

Q. And on this page 68 of his deposition, Dr. Harrison does not make any reference to Fairchild ACMs or Turbo Commander aircraft; is that right?

A. He does not. But my firm impression is that it would include, as I just stated earlier, the fleet that would include a 690.

Q. And by fleet, you're not referring to a particular aircraft manufacturer's fleet, like the Boeing 757 or the Turbo Commander fleet of aircraft, you are referring, as I understand it, to all of the aircraft on which similar events have been reported; is that right?

A. Correct. The fleet is a common term in aviation used by the FAA and others in magazines. It's the fleet of aircraft. And we've narrowed it to those that have these cabin issues.

Q. And you'll agree with me that not all of the aircraft that you're referring to use Fairchild ACMs?

A. They do not.

Q. And the next reference?
A. Is on page 70. "I think there's substantial evidence from bleed air contamination events, as well as other neurotoxic exposures that there can be chronic and persistent effects following acute exposure."
So this, again, tells me from this doctor's testimony that the fleet, as I've described it earlier, there's a problem within it having to do with cabin contamination.
Q. And, again, in this passage that you just read for us from Dr. Harrison's deposition, he does not cite or reference aircraft with Fairchild ACMs; is that correct?
A. He does not. But my impression, as earlier stated, was it includes the whole fleet of those.
Q. Regardless who manufactured the air cycle machine, if there was one.
A. That's right. Well, there probably are in all of these, I would imagine. But he doesn't take --
Q. But --
A. -- can't make any measurements --
Q. Let me ask --

A. -- reference to that.
Q. Sorry, I didn't mean to step one your answer.
A. I guess.
MR. PALMINTIER:
You're doing fine. Just answer the questions.
BY MR. ODELL:
Q. Not all aircraft use air cycle machines, correct?
A. That's right.
Q. And to your knowledge, have there been cabin fume events on aircraft that do not have air cycle machines?
A. Of course, I've experienced them myself.
Q. What aircraft have you been on in which you experienced a fume event?
A. Now, you need to define fume event for me now.
Q. Okay.
A. Because what you've done is expand fume event into anything. We're looking, as far as I understand it, into TCP that would be in turbine engine oil.

Q. In answer to my question, you said you've been on one yourself. And so tell me what you meant by that?

A. What I meant by that, because you didn't define what fume event exactly meant, you expanded the issue. I've been in aircraft where oil, you know, has been gotten loose in the engine and some fumes came in the cabin. Some fighter aircrafts that I've flown that have exhaust pipes right outside your window, and it gets in you cabin, things like that, those are fume events, too. But here, I think we're concerned about Triorthocresyl Phosphate in turbine oil, not just general fume events.

Q. Of the fume events that you just described that you had been an actual participant in, how many, approximately, have you personally been involved in?

A. 40, I think.

Q. That was quick. Did you make a count of that prior to today's deposition?

A. No. I just know how many times I've been in the cockpit of certain planes because I kept track of it.

Q. And were those 40 fume events that

you've described all of approximately the same duration?

A. Oh, maybe. I don't know. Didn't keep track of it.

Q. Approximately how long would that have been?

A. I don't know because I'm mainly using my nose as a sensor and not anything else. So just some minutes.

Q. Have you personally experienced any deleterious health effect as a result of those?

A. No, because it wasn't Triorthocresyl Phosphate, it was not turbine oil.

Q. How do you know that the fumes that you smelled did not contain Triorthocresyl Phosphate?

A. Because I put the oil in the aircraft engine myself.

Q. And the oil that you put into the aircraft did not contain TCP?

A. That's correct.

Q. Did you make a conscious decision not to use oil containing TCP?

A. Never even thought about it because it would be an inappropriate thing to do. TCP is

in oils for reasons having to do with turbine engines, not the kind of -- not internal combustion engines, auto cycle engines like -- like I -- I have.

Q. These were not jet engines on the aircraft that you were -- experienced these event?

A. They were not jet engines.

Q. TCP or Triorthocresyl Phosphates are also a component of other chemicals besides engine oil, correct?

A. Say that again, please.

Q. TCPs are found in chemicals other than engine oils, true?

A. I don't really know for sure. Probably they are, but I don't really know.

Q. Do you know that TCPs are a common component of certain polymers?

A. They may be. May be pesticides, I'm not certain.

Q. What's the next reference that you identified during our break.

A. This is Probst.

Q. This is the deposition of John Probst?

A. Yes.
Q. September 5, 2012, is that right?
A. That's it. Page 36. It says, "You know Tom Farmer? I do. Question: He testifies about a call. He had spoken to a number of people around the country who told him" -- let me back up again -- "what type of engines" -- well, from this brief thing I just said, I took it that he had talked to other people who had had fume events, and probably in 690s. That was my impression.
Q. Who had talked to other people?
A. I think he's talking to Farmer -- I'm sorry, Probst here.
Q. From his testimony, page 36 of his September 2012 deposition, you got the impression that Mr. Probst had spoken to other people that had fume events on other aircraft besides the one at issue in this case?
A. That's the impression I got from these words that I read, yes.
Q. And read those words for me again.
A. This is a question. He testified about a call he had. This is Farmer. "Spoken to a number of people around the country who'd told

him that." Then he says, "Let me back up."

Q. Told him what?

A. Well, he doesn't say. "Let me back up. What type of engine does the airplane have? It's a Honeywell engine. It depends on the engines you're talking about." So it goes off on the TTE 331 engine, dash 5 and all that. But from these few words, I got the impression that Mr. Farmer had related to Mr. Probst or someone that he had talked to other people about these events. That's the impression.

Q. There's no reference in that passage to the Fairchild BUR-20 ACM, correct?

A. Not in these particular words. But I think the subject of this deposition had to do with that.

Q. But in this passage that you referenced, they're actually talking about Honeywell engines and not Fairchild ACM, correct?

A. Well, they said what engine did it have? It was question of that. That's all it was.

Q. And just so they we're clear. Mr. Probst doesn't say that he or Mr. Farmer, in this passage, have any familiarity with fume

events related to a Fairchild ACM, correct?

A. Not explicitly, but I took that as an impression, as I've said now three times, that he had called around to talk to about this. So that's my impressions.

Q. That Mr. Farmer had?

A. Mr. Farmer, and then related it to somebody, maybe Probst.

Q. Okay. And in Mr. Probst's retelling of a conversation with Mr. Farmer, he does not say that Mr. Farmer was specifically referencing Fairchild ACMs, correct?

A. That's correct, not on this page.

Q. Okay. And what's the next reference?

A. It's on Probst again, on page 68.

Q. Same deposition?

A. Yes.

Q. And what does he say?

A. "Turn up the heat all the way. You have air blowing on high heat, have the engines running at full power. It will cook the ductwork every time. Everybody that's familiar with Commanders knows that. So they don't do it, we know better than that."

So that -- I took the impression from that that it's insofar as Turbine Commanders are concerned, you know there's an operating limitation. Even though you can put the lever full forward, they've learned not to do that. And that speaks to me as a possible defect in design maybe with the ACM within the system.

Q. Now, Mr. Probst doesn't actually reference the ACM in that passage, does he?

A. Not here. But he's talking about the airplanes with that, apparently, in there.

Q. In the passage that you read for us, he actually references cooking the ductwork if the flight crews selects the heat too high, correct?

A. On the ground, yes, he does.

Q. Okay. And did Fairchild manufacture the duct work in this airplane?

A. No. I believe the answer is no.

Q. Did Fairchild manufacture the temperature control in this airplane?

A. I do not know.

Q. Mr. Probst does not say, for example, that if you turn the heat too high, it will cause the ACM to malfunction or to put oil

into the cabin atmosphere, correct?

A. Not explicitly so. But this paragraph says that to me, they stated that earlier, something's wrong with the operating limitations or with the design of the AMC. Something isn't getting cool as I would expect it to be.

Q. And would you also agree that depending on the temperature setting on the Turbo Commander aircraft, some amount of form bleed air will enter the cab directly without even passing through the ACM?

A. Could be, yes. It depends on the setting, I'm quite sure.

Q. And that amount of warm air that bypasses the ACM is greater the higher that the temperature is selected, right?

A. I don't know for sure. It may or may not be. I haven't study the process flow of this because those requested documents were never received.

Q. And from your review of Mr. Farmer's deposition, do you recall that Mr. Farmer complained that the temperature control on this particular aircraft did not function properly?

A. I believe I recall something about that, that he was replaced or possibly it's the one where they moved it away from the outside of the airplane skin because of the temperature effects. But I believe all that was done while on the ground running, however.

Q. I believe, and we can look, but I believe Mr. Farmer's testimony was that the temperature control in this plane ran hot and was never fixed. Does that sound right?

A. No.

MR. PALMINTIER:

Form.

BY MR. ODELL:

Q. Why don't you look -- and hold your place on Mr. Probst's deposition -- and just take your report, if you would, Exhibit 1.

A. Uh-huh (affirmative).

Q. And you've attached some pages from Mr. Farmer's deposition to your report, which I believe is PAI 12. Do you have that?

A. Yes.

Q. And turn to page 10 of the deposition, which is excerpt to the PAI 12.

A. Uh-huh (affirmative). Okay.

Q. Do you have that, sir?

A. Yes.

Q. And if you look at -- we'll cover this in more detail, but just calling your attention to the points that I just raised. The fourth paragraph on page 10 reads, "And for a long time" -- this is Mr. Farmer talking -- "which we complained about and it was never fixed, the temperature control would go full hot, and, basically, just like I said, cook the ductwork and overheat everything. And that's where you get the smoke also."

Does this refresh your recollection that Mr. Farmer testified that the temperature control was never fixed on this aircraft?

A. That's what it says here. But I recall it being somewhere in the documents that it -- maybe not at this time, but it eventually was fixed.

Q. Okay.

A. Which is what my testimony was earlier, too.

Q. And if you look at the paragraph before that, Mr. Farmer says, and this is under oath, "When you're at the higher altitude where

it can be, you know, minus 20 degrees would require more heat and more air for the pressurization. And at some point that system in that aircraft will use direct bleed air into the cabin without going through the air cycle machine to augment the cabin pressurization and heat."

And that's what I asked you about a few minutes ago, right, that if the temperature control is selected for hot, sometimes a certain amount of hot air, bleed air will bypass the ACM altogether before entering the cabin, correct?

MR. PALMINTIER:

Object to the form. Asked and answered. Are you asking him the same question again?

BY MR. ODELL:

Q. Correct?

A. Well, I think my testimony was that you can get bleed air bypass in through the ACM. So I think it is in agreement with this paragraph.

Q. And Mr. Farmer believed that if you did that and the temperature control was full hot, you would cook the ductwork, and that's where you get the smoke, right?

MR. PALMINTIER:
Object to the form.
BY MR. ODELL:
Q. That was his testimony here?
A. He said that.
Q. And, in fact, that was also Mr. Probst's belief about the source of the smoke, wasn't it? That the ductwork was cooked by running hot air through it?
MR. PALMINTIER:
Object to the form. We going to have to read the whole deposition again or --
MR. ODELL:
No, I'm asking the witness a question. You can object and he can answer.
MR. PALMINTIER:
I have, but are you going to read it like you did for the previous ones?
MR. ODELL:
Would the court reporter read my questions back, please?
(Record read)
MR. PALMINTIER:

Form, objection.

A. At one point he did say that, but he still sent the ACM off for repair.

BY MR. ODELL:

Q. Did you consider the possibility raised by Mr. Farmer and Mr. Probst that the fume events were, in fact, caused by overheated ductwork and not by leakage from the ACM?

A. Sure.

Q. And did you accept or reject that theory?

A. We basically rejected it by the best information I have. And, again, I'll say that documents were requested but never received. We had very poor drawings to look at. That material, such as I'll just use the name Scat duct, it's is very common in aviation, I believe is probably what they used.

Q. I'm sorry. Say that again.

A. S-C-A-T, Scat duct. It's silicone based. It's good for temperature for 550 degrees Farenheit. And I just didn't believe that there was 550 degree Farenheit air coming out of the cabin hitting somebody in the face or in the feet. Didn't believe it. So we tended to not

pay too much attention to that, but we did look at it.

Q. The silicone in the Scat duct material --

A. Uh-huh (affirmative).

Q. -- as I understand it, you say was, what, supposed to perform without being degraded up to 550 degrees?

A. That's what the manufacturer says.

Q. Okay. And you don't know, but you believe that may have been a material used inside the ductwork on this aircraft?

A. That's correct.

Q. Might it also have been some other material?

A. I doubt it because I talked with Pacific Palm at our -- overhaul -- at our Part 145 operation at the airport, and he did not indicate that. I asked him that question, and he thought it was the Scat duct.

Q. You did not inspect the ductwork on the 690 to see if it was, in fact, made of Scat duct, correct?

A. That's correct. I have not seen one.

Q. Did you contact the manufacturer of the 690 to verify whether it was Scat duct?

A. No.

Q. Did you undertake any research, other than talking with Mr. Palm at the Baton Rouge airport, to verify whether the air ducts on the incident aircraft were made of Scat duct?

A. That's correct. We were waiting on the drawings, and they never showed up for this system, which were not received.

Q. Who did you ask for those drawings?

A. Mr. Palmintier.

Q. And it's your understanding that the drawings, whatever drawings you're referring to, would indicate whether the ductwork was made of Scat duct?

A. Not all of it, just parts. Most of it's metal. But there are connecters, and some parts that have the Scat duct on it -- silicone, basically made of sand.

Q. Is it made entirely of sand?

A. No, they have some other things in it. But silicone is sand.

Q. Does it contain any TCPs, to your knowledge?

A. I do not know.
Q. So as you sit here today, you cannot definitively rule out the possibility that the fume event observed on May 31st, 2011, resulted from overheated air ducts, as Mr. Farmer and Mr. Probst suggests, correct?
MR. PALMINTIER:
Neither one of -- I object to the form. Misstates previous testimony.
A. I ruled out the Scat duct as being a fume event causation. And that's all I can say about it.
BY MR. ODELL:
Q. You don't even know whether these ducts contain Scat duct, though, correct?
A. Other than the testimony or what I understand is in the case. But you're right, I don't know, because the specifications, drawings, parts lists have never been received.
Q. And because you've never inspected the aircraft that was actually involved in this incident, correct?
A. I don't know where it is, that's right.
Q. And you don't know whether the

ductwork on the aircraft was ever replaced from its original equipment manufactured model of ductwork, true?

A. Probst made some replacements.

Q. So we do know that, in fact, some portion of the ductwork was replaced during its lifetime prior to May 31st, 2011, right?

A. Probst said so, yes.

Q. And do we know what material Mr. Probst replaced it with?

A. I don't recall.

Q. Okay. And how old was the aircraft as of May 2011?

A. In the neighborhood of 30 years.

Q. And had it been under Mr. Probst's care and control during that entire time?

A. No.

Q. Had it had had other owners prior to Northrop Grumman?

A. That's my understanding.

Q. And do you know whether those prior owners repaired or replaced any portion of the air ducts?

A. I don't recall.

Q. And so getting the drawings, the

original equipment manufacturer drawings of the air ducts might not tell us anything about what materials were in the air ducts on May 31st, 2011, true?

A. No.

Q. No, that's not true?

A. That's right.

Q. If the air ducts had been replaced between the time the aircraft was placed into service in May 31st, 2011, the OEM drawings might not tell us what they were replaced with, right?

A. No, I would think just the opposite. It's a certificated aircraft. I believe Mr. Probst to be a good and reasonable mechanic. And he would go to those books, pick out the correct material and replace it properly in accordance with the certification of the aircraft.

Q. When did Mr. Probst make the changes to the duct in the aircraft?

A. I don't know the exact dates. But I did read it in his deposition, however.

Q. Do you know whether it was before or after May 31st, 2011?

A. I don't recall that. Did you want

me to finish the --

Q. Yes, I'm sorry. Let's go back to -- before we move on.

A. There was one more, I think.

Q. Yeah. You found one more reference in our earlier search.

A. In Probst, page 98, near the bottom of the page. It says, "There were actually a lot of problems with pressurization on this airplane. It was pretty common. Well, there are a lot of problems on all of these older aircrafts that maintain pressurization is an issue." And then he had some dates back to 2009 and back in history. I got the impression from this statement that many, if not all, the 690s had trouble with pressurization.

Q. He didn't say anything about fume events there, though, does he?

A. But pressurization is part of that and could be, yeah. But he didn't say that, that's correct.

Q. And there are other things that besides a malfunction of the ACM that could cause pressurization problems, correct?

A. Maybe. But the ACM was the big

thing in that pressurization system. It modulates it.

Q. What are some other things that could cause loss of pressurization?

A. Engine failure.

Q. Anything else?

A. ACM failure. Some of the valves might fail and the air fill close possibly. Probably a few other things that I don't know right now.

Q. Were there any other references you wanted to call our attention to?

A. Nope, that was it.

Q. In your report you attached as an exhibit an article by Jeremy J. Ramsden titled Jet Engine Oil Consumption as a Surrogate for Measuring Chemical Contaminations in Aircraft Cabin Air, which is Exhibit PAI 6 to your report.

A. Okay.

Q. Are you familiar with that?

A. Yes.

Q. And you referenced this report -- well, I can't find it. I'll ask you a different question.

So you referenced this report and

attached it -- this article and attached it to your report. I wanted to call one passage to your attention, which appears on page 115 of the article, which is the second page of PAI 6. At the bottom of the left-hand column, there's a paragraph that begins "An expected feature" -- pardon me -- "An unexpected feature." Do you see that?

A. Yes.

Q. And he's referencing an earlier study by Crump. And he says, "An unexpected feature of the results of Crump, et al, is that the ratio of Triorthocresyl Phosphate, TOCP to total TCP was much higher than what can be deduced from the composition of the modern commercial TCP that is presumably what is blended into the base oil."

And then in parentheses, it goes on to say, (During the past few decades intensive efforts to eliminate TOCP, because of its known potent neurotoxicity, from the commercial product at reasonable costs have been made.) End parentheses. "The reason for this discrepancy is still unknown." Do you see that?

A. Yes.

Q. And then there's a footnote. And the footnote reads, "One possibility not discussed in reference 27 is that there is an additional source of ToCP apart from the engine oil. TCP is used as a plasticizer in certain vinyl polymers. And this provides a possible, albeit, improbable source for the accessed ToCP." Do you see that?

A. Yes.

Q. Do you know whether any polymers in use in the aircraft in May 2011 contained TCP?

A. I have no knowledge.

Q. Okay. If you turn to page 4 of your report, Mr. Hansen, one of the criticisms of the Fairchild BUR-20 ACM that you offered, is that there are no sensors suggested for or provided with the ACM to detect engine oil fumes before they become dangerous?

A. Uh-huh (affirmative).

Q. That's in the last full paragraph on page 4 of 18.

A. Right.

Q. You see that?

A. Yes.

Q. Are you aware of any ACMs

manufactured prior to 1980 that contained sensors to detect and alert the flight crew to the presence of engine oil fumes?

A. No.

Q. Are you aware of any ACMs manufactured since 1980 that contain or incorporate those types of sensors?

A. No.

Q. Have you undertaken any drawings or models to test whether it would be feasible to incorporate such sensors into an ACM for use on this type of aircraft?

A. No.

Q. Are you aware whether anybody else has undertaken such testing or modeling?

A. I don't know.

Q. On the next page of your report, page 5 of 18, in the last paragraph you say that "Additionally high efficiency particulate, and in parentheses, HEPA, H-E-P-A, filters combined with activated charcoal or similar filters could have been installed to remove both particles and chemicals from the cabin air"?

A. Uh-huh (affirmative).

Q. Did I read that correctly?

A. Yes.

Q. Is it your opinion that HEPA filters combined with activated charcoal or similar type filters should have been incorporated into the ACM itself?

A. Absolutely not.

Q. Okay. Where would those filters with activated charcoal have been located in your ideal world?

A. Well, it's not an ideal world. It's a common industrial practice world.

MR. PALMINTIER:

I object to the argumentative nature of the question.

A. Look on page 7, figure 5, it shows a basic drawing of this system. It's an air-conditioning system. And these things that are of supply by Fairchild are a lot more than just the refrigeration unit pointed to there. It's also the primary and secondary heat exchangers, and some piping and probably some ductwork to connect this thing.

If it were me, I would probably find a place in some of these ducts, probably downstream of the ACM itself, where you see that

T connection right here -- I'm looking upside down, I guess -- where is it, right there? Right there? And you'll find, I think, on that disk I gave you some -- something from the industry that shows a can about this big around that would go in there that could be replaced, like the catalytic converter style, something to go right in the pipe.

Q. Do me a favor. You've got a green pen in your hand. On Exhibit 1 --

A. Uh-huh (affirmative).

Q. -- which is your report --

A. Uh-huh (affirmative).

Q. -- in the diagram that you just pointed to, would you put an "X" where you think that filter should go?

A. That would probably be right -- right in here someplace would be one of them. And probably another one for the bleed area. Put here "X," and there "X," something like that might be a good place. Not within the ACM. But as I stated in my report, on ACM equipment.

Q. I'm sorry. I didn't quite understand that.

A. I didn't say that it would -- wanted

to put it within the ACM. I said ACM equipment, which is to me all this stuff shown in figure 5.

Q. Figure 5 is titled Twin Commander Air Conditioning and Pressurization Equipment, correct?

A. Correct.

Q. And is it your belief that Fairchild manufactured all of the components of this system that we see in figure 5?

A. No, I've already told you what I believe that they manufactured. Refrigeration units, primary secondary exchangers, and some of the piping. It's on their drawings.

Q. And it's your opinion, in this case, that Fairchild should have included HEPA filters with activated charcoal at least two points in this system; is that correct?

A. No, it isn't. I said activated charcoal or something similar that would behave like that. In other words, you want to get rid of particles and also something responsive to, say, TCP that would tend to adsorb it.

Q. Is it your understanding that Fairchild designed this system that we're looking at in --

A. Uh --

Q. -- figure 5?

A. -- the entire thing, I know they would participate in the design. They would have had to know what these other things did. But I believe their main effort was in the things that are already listed, which is a refrigeration unit, the cooling turbine, compressor turbine, refrigeration unit, primary and secondary heat exchangers, and related piping shown on their drawings supplied by them.

Q. Now, you said that Fairchild would have had to participate. Do you have any actual knowledge as to whether they did participate in this drawing?

A. Actual knowledge, no. But I've been a mechanical engineer in the industry for 50 years. And I know how this goes. We do these designs all the time. You don't just do something in a darkroom and shove it out the door. You interact a lot with the airplane manufacturer, so if he can close the proper ACM equipment to use in his system. So they would have to know a lot of process design information on a hot air coming in, pressures, all this sort

of stuff they have to know. These are the things we requested that were never received.

Q. And you requested them from Mr. Palmintier; is that right?

A. Yes.

Q. And is it your opinion that if these filters with activated charcoal or some similar type filter had been in place on May 31st, 2011, it would have prevented the fume event altogether; is that correct?

A. Most likely.

Q. But you are not suggesting that HEPPA filter with activated charcoal or a similar filter should have been incorporated directly into the ACM designed and manufactured by Fairchild, correct?

A. Yeah. And you're talking about the ACM, it's this little refrigeration unit sitting right atop here? Of course, I didn't say that. I didn't say it in my report. And it's silly, no one would say that.

Q. Why not?

A. Well, you can't get it in there. It'd have to go outside, as I've indicated here.

Q. And so the aircraft manufacturer

should have made provisions for a filter of that sort in the aircraft's air-conditioning and pressurization system?

A. He may have. It also might have been provided by Fairchild, realizing that there could be fume events. And they maybe should warn them or give them the opportunity to put those things in place. And then once there, they'd also be subjective to process design engineering to make sure they'd work.

Q. But to your knowledge, the Turbo Commander 698 didn't contain a filter of this sort at any point in the cabin air system; is that right?

A. That's my understanding.

Q. In the -- turning back to page 5 of 18.

A. Okay.

Q. In the same paragraph we were looking at before, the very bottom paragraph on the page, you go on to say, "In the interest of safety, Fairchild could and should have produced some FAA supplemental type certificate, STC, to at least install some fume sensors, filters, adsorbers, and/or suggested diverters to

adequately warn cabin occupants such as the plaintiffs." Did I read that correctly?

A. I think so.

Q. Are you aware whether Fairchild had ever received a report of a fume event involving its BUR-20 Air Cycle Machine prior to this lawsuit being filed?

A. I have no knowledge of one.

Q. Is it your opinion that Fairchild's BUR-20 ACM should have incorporated fume absorbers into its design?

A. I already answered that question. No, because you can't get it in there.

Q. Is the fume absorber the same thing as a filter?

A. A little bit like that. They're -- the filter is -- gets rid of particles. An adsorber takes chemicals within, it could be, and I'm just speculating, charcoal, it could be activated. I don't know what it would be. Some substance that would adsorb dangerous chemicals.

Q. You said absorb, A-B --

A. No.

Q. -- in this paragraph, correct?

A. No, I said ad. It should be A-D.

Q. And that's why I'm asking because I hear you saying something other than what's written --

A. Oh, no, no.

Q. -- in the report?

A. I've been very, very clear. I'm being very clear to even correcting her, it's adsorb. It's different than absorb.

Q. I understand. I appreciate the distinction. I'm referring to what you wrote in your report, sir.

A. Where is it?

Q. If you look in second to last sentence of that paragraph that I just read, that says absorb, A-B, does it not?

A. It should say ad.

Q. That's a typographical error?

A. Yes.

Q. Okay. And so the adsorber referenced in your report is functionally the same as the HEPPA filter with activated charcoal?

A. I don't know. I've said repeatedly that it might be activated charcoal. It might be some other chemical that I'm not aware of, that would take TCP and bond it, so that it didn't

past the filter into people's lungs.

Q. And have you designed an alternative system whereby the Twin Commander or Turbo Commander 690A could be fitted with such an adsorber, such that the May 31st, 2011, fume event could have been prevented?

A. I've only suggested it to you and in the report and words and marked it on the diagram. That's all I can say at the moment.

Q. You have not designed such a system yourself, correct?

A. That's correct.

Q. You have not tested such a system since you've not designed it?

A. That's correct.

Q. Are you aware whether others have tested or designed such a system for the Turbo Commander 690A?

A. Not aware of it.

Q. You also mention fume sensors in this same sentence. Have you designed or tested a system of fume sensors for the Turbo Commander that could have prevented the May 31st, 2011, fume event?

A. No.

Q. Do you know whether anyone else has?
A. Not -- no, no knowledge.
Q. Are you aware of any existing supplemental type certificate that would provide for fume sensors, filters, adsorbers, or suggested diverters for the Turbo Commander 690A of the type you're suggesting?
A. No.
Q. You also make reference in this same paragraph to air bearings. And you actually make reference to it in a number of points in your report --
A. Yes.
Q. -- correct?
A. Yes.
Q. And I think I know the answer to this, but I'll check with you. An air bearing, is that the same thing as an air foil bearing?
A. It could be, yeah. I gave an ASME paper to put in here.
Q. And I read that paper attached to your report. And that was why I was guessing that they were the same.
MR. PALMINTIER:
Excuse me.

MR. ODELL:

Do you need to take a break?

MR. PALMINTIER:

I need to take a quick break. I'm going to have to do something on this BP stuff. So off the record.

MR. ODELL:

This is off the record.

(Off the record)

MR. MITCHELL:

Jonathan Mitchell has now sat in for the deposition for plaintiffs.

MR. ODELL:

Still Chris Odell for the defendant. One riot, one ranger. That's how we do it in Texas.

BY MR. ODELL:

Q. Mr. Hansen, you're ready?

A. (Nods head.)

Q. We were talking before we broke about some of the alternative systems that were proposed in your report?

A. Uh-huh (affirmative).

Q. What size would the HEPPA filter with activated charcoal need to be in order to

remove enough of the oil and TCP particles in the May 31st, 2011, fume event to prevent injury to the plaintiff?

MR. MITCHELL:

Object to form. Just to the extent, it would call for expert medical testimony, and he's not a physician.

A. Keep in mind, and I've said in the report very plainly, that these are just suggestions. I just hate to use the words after thoughts, but maybe that's more appropriate there.

How could it maybe be improved? I haven't done a design. You've asked me about that. But these are just suggestions. The real problem we point to in the report very firmly is the ACM is what's at issue. And these other things would have just -- because I think you're supposed to say what you might do to improve it, but these are just suggestions, that's all.

Q. And so as you sit here today, you have not done any of the work necessary to calculate the size or the particular capacity of the filter that you're suggesting; is that right?

MR. MITCHELL:

Object to the form. I think that mischaracterizes what he just said in response to your question.

BY MR. ODELL:

Q. Is that right?

A. I don't have enough data to do it, I don't think. They're just suggestions.

Q. We had started to talk about air bearings before we took our break.

A. Uh-huh.

Q. And on the same page, page 5 of 18 of your report, same paragraph, first sentence in that paragraph. You state, "Modern design practices for ACM equipment avoids the use of turbine engine oil lubrication systems entirely, instead using air bearings and ceramic hybrid bearings." Did I read that correctly?

A. Where are you? Yeah, I think you did but --

Q. Sorry, first paragraph.

A. Here? Okay. I think so.

Q. When did these modern design practices incorporating air bearings and ceramic hybrid bearings begin for ACM equipment?

A. Well, just, again, I think some

years go. And that's stated in that ASME paper. Maybe there's some dates that may be -- I don't remember what they were but --

Q. After 1980?

A. I'm not sure, probably. But I'm not certain. I'd have to look through the paper.

Q. You agree with me that air bearings and ceramic hybrid bearings for air cycle machines were developed after the first BUR-20 was developed in the early 1950s?

MR. MITCHELL:

Object to the form. Compound.

A. Most likely.

BY MR. ODELL:

Q. Were air bearing ACMs the standard in 1973 when the 690A was first type certificated?

A. I have no knowledge.

Q. How about ceramic hybrid bearings ACMs?

A. No knowledge there either.

Q. Are you aware whether any air bearing ACM is approved for use on the 690A?

A. I have no knowledge of that either.

Q. Same question about ceramic hybrid

bearing ACMs. Do you whether there are any ceramic hybrid bearing ACMs approved for installation on the 690A aircraft?

MR. MITCHELL:

And I'm going to object to the word approved. And I apologize if this is just my absence causing this problem. But have defined approved? Approved under what circumstances, approved by what agency or authority?

BY MR. ODELL:

Q. You understand the question, Mr. Hansen?

A. Well, I suppose. But I understand his request, too.

Q. He's making objections for the record. Do you understand the question?

A. I'm not certain that I do.

Q. Okay. Let me ask it again.

A. All right.

Q. Do you know whether there are any FAA type certificated ceramic hybrid bearing air cycle machines for the 690A aircraft?

A. I have no knowledge.

MR. MITCHELL:

Thanks for making that
clarification.
MR. ODELL:
My pleasure.
BY MR. ODELL:
Q. But you will agree that the Fairchild BUR-20 ACM is type certificated for this aircraft?
A. Yes, I think so.
Q. And you know what an airworthiness directive is?
A. Yes.
Q. What is an airworthiness corrective, to your understanding?
A. It's a requirement of the FAA to fix or replace something.
Q. You're aware that airworthiness certificates are -- strike that.
You understand that airworthiness directives are often issued by the FAA when an unsafe condition has been identified in an aircraft component?
A. I wouldn't use the word often. I would say occasionally.
Q. Okay. To your knowledge, are there

any airworthiness directives that have ever been issued by the FAA in connection with the Fairchild BUR-20 ACM?

A. I didn't find any.

Q. You looked though, right?

A. Yes, I did.

Q. In connection with your work on this case, have you attempted to retrofit a 690A aircraft with an air bearing ACM?

A. No.

Q. Do you know whether a -- an air bearing ACM exists that could be retrofitted onto a 690A aircraft?

A. Existing at this moment?

Q. Yes, sir.

A. I know of none, other than what's indicated in the ASME paper, that's possible.

Q. But you don't know if any of them is type certificated for the 690A?

A. I do not know that.

Q. Same question with respect to a ceramic hybrid bearing. Do you know whether there are any ceramic hybrid bearing ACMs type certificated for the 690A aircraft?

A. I don't know that they are.

Q. And you have not, as part of your work on this case, undertaken any drawings or models of such an aircraft to see whether it would be's feasible to retro -- strike that. Used the wrong word.

A. Okay.

Q. In connection with your work in this case, you have not undertaken any drawings or models to test the feasibility of retrofitting the 690A aircraft with an air bearing ACM, correct?

A. That's correct.

Q. Or ceramic hybrid bearing ACM, correct?

A. That's correct.

Q. And in any event, before a new type of ACM could be installed on the Turbo Commander 690A, it would have be to type certificated by the FAA, correct?

A. I believe so.

Q. Are you familiar with that type certification process?

A. Yes.

Q. Fairchild couldn't just whip up a new design for the ACM and install it on the

aircraft without first getting it type certificated or getting an equivalency from the FAA, correct?

A. That's my understanding.

Q. Have you performed any economic analysis of the economic feasibility of making these suggestions that are set forth in your report?

A. No.

Q. Do you know whether anyone else has?

A. No.

Q. Do you have any understanding what the market was for Fairchild's BUR-20 ACMs as of May 2011?

A. No.

Q. Do you know whether they were still in manufacture; that is, whether Fairchild was still making new ones as of that date?

A. My understanding is they stopped making new ones 1980.

Q. And did you take that into account in formulating your opinions in this case?

A. Sure.

Q. How so?

A. Just general background knowledge.

Q. Now, I remember what I was going to ask you. The Ramsden article that is attached to your report as PAI 6 makes a number of references to chemical contamination and aircraft cabin air, correct?

A. I think it does, yeah.

Q. Do you know whether any of the aircraft that are the subject of those chemical contamination examples used Fairchild ACMs?

A. I don't know.

Q. I wanted to ask you about another study attached to your report. And this is -- the next one that follows by Sarah McKenzie Ross. This article is entitled Cognitive Function Following Exposure to Contaminated Air on Commercial Aircraft, a Case Series of 27 Pilots Seen for Clinical Purposes.

A. What number is that, please, PAI what?

Q. Well, I don't know. It's the one that immediately follows the Ramsden article, but doesn't have a little number attached to it.

A. Okay.

Q. If you look at Exhibit 1, it might be easier. Do you have it in front of you, sir?

A. Yes.
Q. Who found this article?
A. One of the other engineers in the office.
Q. Did you review it?
A. Oh, I read it briefly, yes.
Q. Was it your decision to attach it to your report?
A. I would say yes. Let me see if I can find it and see why we did it. I see it here.
Q. Did you rely on this report in forming your opinions in this case?
A. I considered the report.
Q. You see the section titled Introduction, begins at the bottom of the first page of the Ross article?
A. Yes.
Q. I'll just read the first two sentences to you. It says, "To enable passengers and crews to live in a reduced pressure environment, aircraft cabins are pressurize and the air supply to the passenger cabin and cockpit is suppled from the engines or auxiliary power units. This air is unfiltered and known as bleed

air, and is sometimes contaminated with hydraulic fluids, synthetic jet engine oils and/or the compounds released when these fluids and/or oils are heated or pyrolized; for example, carbon monoxide, phosphorus oxides, aldehydes." Did I read it correctly?

A. Yes.

Q. It makes reference to the fact that this air is unfiltered, correct?

A. Yes.

Q. And so you would agree with me that the 690A is not the only aircraft in use today that does not filter the bleed air before it is directed into the cabin, correct?

A. Likely not.

Q. And then if you -- it goes on to discuss contaminated air events. And the last sentence in that paragraph says -- the last two sentences says, "It is recognized that all aircraft are subject to engine oil leaks occasionally. But certain types of aircraft record statistically more events than others. These include the BAE 146, A320 and Boeing 757." Did I read that correctly?

A. Yes.

Q. Do you know whether any of those aircraft types use Fairchild ACMs?

A. I don't know.

Q. You would agree with me that air cabin contamination issues are not unique to aircraft featuring Fairchild ACMs?

A. I agree with you.

Q. And, in fact, air cabin contamination issues are not unique to aircraft that have ACMs at all, true?

A. Occasionally.

Q. The next sentence says, "The incidence of contaminated air events on commercial aircraft is difficult to quantify as commercial aircraft do not have air quality monitoring systems onboard." Did I read that correctly?

A. Where are you reading that?

Q. The very next sentence, on top of page 112.

A. Point to it. Oh, that one right here? Okay.

Q. I'll read it again for you.

A. I can read it. That's right.

Q. You agree with that statement?

A. I don't know whether agree or disagree. It just -- I see it here, and I tend to believe it.

Q. Now, one of the suggestions that you made in your report was that the Fairchild ACM should have incorporated a sensor to detect and alert the flight crew to the existence of potentially toxic fumes. But this Ross article that you've attached seems to suggest that commercial aircraft don't have air quality monitoring systems as a rule; is that correct?

MR. MITCHELL:

I just object to the question in general. It seems to give two facts, but no really a connection between them. So I guess compound is my objection.

MR. ODELL:

Thank you for the speaking objection. You can answer the question.

A. Well, the first part of it is answered no. And the second part is that according to this article, many don't, is what I think I'm reading here.

BY MR. ODELL:

Q. And is that what it says?

A. Only 61 out of -- well, it doesn't say that all aircraft don't have it. It just says do not have it onboard, under reporting is a concern of theirs, I think.

Q. Well, let me short circuit it. Which aircraft, which commercial aircraft in use today contain onboard air quality monitoring systems?

A. I don't know.

Q. Are you aware of any?

A. No, other than the test airplane, the 690. When they took it up for testing, they had air quality equipment onboard.

Q. But you're not aware of any commercial aircraft in use today that is part of their type certificated design incorporates an air quality monitoring system, correct?

A. I'm unaware of it.

Q. We talked a little bit about air worthiness directives a few minutes ago. And I believe your testimony is that you couldn't find any air worthiness directives directed at the Fairchild BUR-20 ACM, correct?

A. That's right.

Q. Are you aware of any determinations

by the Federal Aviation Authority or any governmental body that the BUR-20 ACM is unsafe?

A. I'm unaware.

MR. ODELL:

Let's take a little break. Let me look at my notes.

(Short break)

BY MR. ODELL:

Q. Now, Mr. Hansen, we were talking about air bearings, foil bearings earlier in your deposition. You recall that? Would you agree with me that cabin air quality was not one of the reasons for the introduction of air bearing ACMs?

MR. MITCHELL:

Object to form. He needs to speculate to that question as to the knowledge of others.

A. As I recall, the ASME paper reliability and, therefore, safety were the main reasons. I don't recall in that article if they talked about air quality. I just don't recall.

Q. Have you undertaken any study to determine whether Fairchild BUR-20 ACMs are more prone to oil leaks than any other ACM on the market?

A. No.
Q. Are you aware of any such study?
A. No.
Q. So you're unable to say, as we sit here today, whether the Fairchild BUR-20 ACM is more susceptible to oil leaks than any other ACM on the market, correct?
A. That's correct.
MR. ODELL:
No further questions. Pass the witness.
MR. MITCHELL:
I don't have any questions.
RE-EXAMINATION
BY MR. ODELL:

Q. Earlier in your deposition, Mr. Hansen, you pulled out a couple of documents from your binder. One is the expert report of Paul Dziorny that was served on the plaintiffs by the defendants in this matter. Have you reviewed Mr. Dziorny's expert report?
A. I read it, yes.
Q. And was there any aspect of this report that you disagreed with?

A. Well, there were a few things in there, one of them that we've already covered. He said I wanted to put all this filtering stuff inside the ACM itself and that's -- I refer to that as silly and I didn't do that. There are probably some other things too, I just don't recall sitting right here.

Q. There's nothing else that you can recall that you took objection to or disagreed with?

A. I just don't recall it sitting here. I'd have to start reading it and see if I can find something, but, no, I don't.

Q. And we'll get to that in just a minute. The second document that you pulled out is the March 4th, 2016, report prepared by Matthew D. Lykins on behalf of the defendant in this case. Have you reviewed that report as well?

A. I looked at it, yes.

Q. And did you have any objections or disagreements with any of Mr. Lykins' conclusions?

A. There were a few of them.

Q. Tell them to me please.

A. Well, I have to start reading these things and just call them out if that's what you want to do.

Q. Let's mark the Lykins report as Exhibit 2. Why don't you take a look and tell me what in the Lykins report you disagreed with. And if you'd prefer to go off the record to review it, let me know.

(EXHIBIT NO. 2 IS MARKED.)

A. No, this is fine. The overall impression of this report and that of Mr. -- is it Dziorny?

Q. I think it's actually pronounced Journey, like the band.

A. Wow. I struggled over that.

Q. I would haven't guessed it myself.

A. Neither of them are failure analysis reports, where you throw out the improbable, keep the probable use Occam's razor and try to find a good answer. They're mainly just -- recant how the ACM is made and say that nothing different can happen. So I thought that rather unusual. Also, Mr. Lykins is -- he is a certificated mechanic but his experience is mainly in avionics or radios. He owns a radio shop, Part 145

avionic repair station.

Q. Okay. So you think he's not qualified to reach the conclusions that he does?

A. May not be.

Q. Mr. Lykins is a -- according to his CV, an AMP certified engineer as you are, correct?

A. No, it's certified mechanic.

Q. Sorry. Certified mechanic, correct?

A. That -- he says that but then his experience is not airframe and paraplane, it is radios.

Q. Where are you looking?

A. On page six near the top. Owns and operates an FAA certificated Part 145 avionic repair station, performing avionics tests and inspections of aircraft across the United States.

Q. And that's the basis for your --

A. Yes.

Q. -- conclusion that --

A. I'm sure he's a very nice person, and well, I just found that odd.

Q. Because he has expertise in electronic and avionics repair you think that he would not have any expertise in environmental

control systems; is that right?

A. Not necessarily just that, but the ACM as a mechanical device.

Q. Okay. Anything else in the Lykins report, Exhibit 2 --

A. I'm reading --

Q. -- that you disagree with?

A. I'm reading it right now. It's going to take a while to get through it.

Q. Okay. Take your time.

A. On the bottom of page six he talks about Probst's deposition. We've already been over that issue where he sort of cherry picked some of the lines of that deposition and left other ones out. We studied that already.

Q. Okay. Anything else?

A. And there where it says at the bottom, inspected 50 flight hours and looked at the oil level again and it was still where it was, he says. But no one seemed to know if anybody ever checked it or added oil during the 50 hours, that's not stated.

Q. Have you seen any indication that oil was added between the time that it was checked prior to May 31st, 2011, flight and the

when it was checked on June 24th?

A. I see no indication of it but that's something you always do, you check the oil in the engine, you check the oil in this before you -- it's a preflight. They talked a little bit about the -- on the second page, seven, they checked the drag on the ACM at 1 1/2 inch pounds of torque to rotate. And an engineer from Fairchild said 10 inch pounds was sufficient, that shocked me. 10 inch pounds is almost a foot pound. I owned and operated and worked on and flown turbine airplanes for quite a while and you have to turn them with your finger. I mean, to have that much drag on something is -- says to me that there's a blade past rub, bad bearing, something wrong in there. I found that quite remarkable.

Q. At 1 1/2 inch pounds or at 10 inch pounds?

A. Well, the 10 for sure. The 1 1/2, not so sure. Because I can recall just the preflight on the turbine engine was to turn the air compressor with your finger to see if it moves.

Q. Anything else?

A. Well, they say that nothing leaked

because they didn't find any -- after 55 hours, the same level of oil. But we've already talked about that, we didn't believe that. On page seven he quotes somebody's deposition -- oh, that's me.

Yeah, I saw in some of the -- I think it was in Farmer, page 47 or 48 or something like that, I believe I remember him showing that they had some oil problems before the incident and then after. And then of course with the Serial 335 they had one oil event too, fume event.

Q. Oil problems on the ACM installed in the aircraft?

A. I believe so.

Q. And you recall that from Mr. Farmer's deposition; is that right?

A. I think so. I don't recall.

Q. Mr. Probst's testimony as we've discussed at some length today was that the -- the ACM installed on the aircraft on the date of the May 31, 2011, incident, showed the same oil level before and 50 hours after, correct?

A. That's what he said, yeah, and I doubt this.

Q. But you don't have any reason to doubt it, right?
A. Well, sure.
Q. You don't have any facts to the contrary?
A. No facts to the contrary other than just experience.
Q. Okay.
A. On page 10 he says on page 6 that I theorized the ACM was a possible source but didn't establish it. I think that I have. It's my opinion to disagree with that and I further stated it in the deposition today.
Q. Anything else?
A. I'm still reading. He says I didn't look at the ducts overheating and emitting smoke and -- I did but I didn't say anything about it in the report so I understand why he said this. Now, the second thing down on page four of my report he claims -- this is still on page 10 -- the only way for clean outside air to arrive in cabin is through the ACM. And I gave a reference for that. I was really quoting -- I guess was Farmer, I can't remember who it was. But I gave a reference 12c to that. I was really quoting

him, I didn't -- I do understand that there's a bypass air and the air through the ACM.

Q. Anything else?

A. Well, he says too that I wanted to put the fume sensors and filters and adsorbers and stuff them inside the little ACM. I didn't say that, we discussed that already.

Q. You believe that they should've been installed elsewhere in the environmental control system, correct?

A. Yeah, some appropriate place. On the second paragraph on 11. It says my proposed alternative design of fume sensors, filters, absorbers -- he says absorbers and it should be adsorbers -- and diverters of whatever are unproven and would fail to warn -- he says they would fail to warn but he doesn't know that because he didn't produce the design himself or even tried to.

Q. Nor did you though, correct?

A. That's right. Except for all my experience industry. Sensors, filters, diverters, adsorbers are all over the place in the American industry and --

Q. But not commercial aircraft?

A. Not necessarily but they certainly could be and that's the issue here. We suggested they should maybe do that or maybe have an ACM that doesn't have oil inside of it. And we did find one of the -- I think I mentioned this already too, a patent where they had the bearings on the outside of the unit that were lubricated with grease. I thought that rather important.

Q. Why is that important?

A. Because you don't have turbine oil inside the ACM where it could get into people's lungs.

Q. Was the purpose of that innovation to prevent cabin air contamination?

A. I don't know. It didn't -- I don't think it says that in the patent, it just talks about it being an advantage and I agree with them. I like the basis of the design.

Q. Do you know whether that design ACM would be compatible with the Turbo Commander 690A?

A. You can't just bolt it right on. There would be some modifications made but I would assume it can certainly be made to be compatible. I don't know why not.

Q. It would require a supplemental type certificate before it could be installed in the aircraft though, correct?

A. It may, it depends.

Q. It would have to be tested and so forth to ensure compatibility?

A. I'm not sure of all that but you would think so. And the last paragraph on 11, it says, "I proposed alternative design of replacing the oil lubricated ACM with a oil-less which would fail to protect aircraft occupants from toxic engine bleed air entering the cabin." And that's right, that one thing is correct but what's wrong with putting the filter in the bypass air. So, you see, he cherry picked that out and didn't say the whole thing. He didn't allow for all circuits that would go into the cabin.

Q. Because you would have put it downstream of both the ACM and the bypass so as to catch any contaminants in the system; is that correct?

A. It might do that. Each individual one would have it's own sensor, adsorber, filter or whatever it turns out to be.

Q. But not as a component of the ACM?
A. That's right. You don't stuff it inside. You can't get anything else in there.
Q. Okay. And anything else in Mr. Lykins report that you --
A. Nothing comes to mind at this moment as I sit here today.
Q. Okay. Let me -- before you pick up Mr. Dziorny's report let me stick an Exhibit 3 sticker on there.
(EXHIBIT NO. 3 IS MARKED.)
A. Okay.
Q. Is there anything in Mr. Dziorny's expert report in this case that you disagreed with or objected to?
MR. MITCHELL:
You don't have an extra copy of that, do you?
MR. ODELL:
One minute.
MR. MITCHELL:
Thank you.
A. I got the impression from his report -- it doesn't have page numbers but his bold heading was C, talking about the Fairchild Air

Cycle Machine.

BY MR. ODELL:

Q. Yes, sir.

A. This particular BUR-20 sort of shunted off to the side and put in the shop of a PMA, Parts Manufacturer Authorization, place, I guess just for the purposes of overhaul. I don't know if they even make new parts anymore. So they're continually using older parts which I think is a mistake.

Q. That was your impression from reading this?

A. Yes.

Q. Or do you know that from some other source?

A. No, from reading this. That's in Fairchild -- correction, Frederick, Maryland.

Q. Okay. Anything else, sir?

A. Paragraph 17, there's a couple of the diagrams that I had in my report he put in here. And what he did was take a bluey lips and stick it around the ACM machine claiming I didn't identify it, which is not correct. If you'll look it was already identified. You can't read the words up there. We've been over this also in

the deposition that that was the refrigeration machine is pointed to which includes the scope of supplies I've already testified, the ACM, the exchangers, some piping and so forth as indicated on the drawings.

So when I say ACM system or equipment, I meant the whole thing and he tried to make it like I mean just the little piece itself.

Q. Okay. Anything else in Mr. Dziorny's report?

A. Paragraph 20, he again refers to my report and -- we found a colored drawing off the internet which we put in here just for, like, an example, Mechanical Flow Diagram for a Common ACM System. We thought just to help people understand how the flow goes, the mechanical flow diagram. And he faults that saying that the Fairchild system isn't like that. Well, that's -- he follows it and once we didn't say it was.

Q. You don't disagree that the flow diagram in Figure 2 is different from the actual flow diagram of the Twin Commander 690A with a Fairchild ACM?

A. Of course not. I even said so, it was an example mechanic for a common. So something just any -- just a common -- just so we didn't have to draw it ourselves. We we're in a hurry to get this out and we just picked that off the internet to use.

Q. Anything else in the Dziorny report that you disagreed with?

A. He repeats the only way for clean outside air, quote, thinks that I don't know the bypass but I do. I just -- maybe I should have worded it a little bit differently but I was trying to quote someone else's impression.

Q. You're looking at paragraph 22 of the Dziorny report?

A. That's right.

Q. Anything else?

A. I'm still reading. It will be a little while on this one, it's longer. Number 24 on the following page there. He says that the oil compartment holds 37 ccs of fluid and it's filled by adding oil through an oil port until it over -- an overflow occurs. And then he says since 37 ccs of oil is contained in the unit, the oil level reaches the top of the port and it

can't be overfilled.

Well, we took our exemplar and pumped it with water in there and then we noticed that there's probably -- you can hardly tell this from a drawing to see the parts drawings don't reflect anything about venting. They don't reflect anything about how you amount this fill valve or filled fitting -- they call it two different things so we don't know if there's two parts or one part or what. Well, I made -- it's in my report I think. It may be that -- here's the unit and on top of heat exchanger they've got little L-brackets sitting over there, you can hardly see this in the drawings we had. We just surmised that thing is sitting out there and there's some tubbing that goes over here. So believing this we found it held 57 ccs, the whole unit. So there's a lot more oil. He says well, it can only lose 37 ccs of oil, that's 555 drops -- it's over 800 drops are in there. So that was erroneous.

Q. So that's not just the oil compartment on the ACM however, that's including the --

A. All the piping and --

Q. -- tubing and piping attached to it?

A. -- that thing over there that -- which I don't have a drawing for it.

On 25, he complains about us saying too much oil can be in there. So at the time we had water in it, we subjected the ACM to some mild aircraft turbulence, which is what I had mentioned in my report. Shook it a little bit and water comes out and it gets over in the shaft space and if you'll look --

Q. Let me see if I understand this. This was not an ACM that was actually installed in an aircraft, this was your exemplary ACM?

A. Yeah, I don't have the other one.

Q. And so you took the exemplar ACM, which is disconnected from any actual aircraft and shook it a little bit to see if you can get water to come out?

A. Yeah.

Q. Okay. And you got some water to come out?

A. Sure.

Q. And based on this it's your conclusion that oil would come out of the ACM under turbulence conditions?

A. Yes.

Q. Okay.

A. Of course it would. It would not necessarily come out of the unit so much but get up into -- what I call the shaft space above which is suppose to be sealed off but isn't and it got up in there.

Q. And did that happen? You tested it with water not oil, correct?

A. Yeah.

Q. And did water get up into the shaft space?

A. Yes.

Q. How much?

A. We don't know. We just -- some got up in there. We just didn't spend a lot of time doing this but --

Q. You didn't measure it?

A. We calculated the -- with the shaft in place, it can hold almost 14 ccs. And if you look on our drawing -- I'm sorry, photograph on my page 6 of 18, you see a bunch of white artifacts of oil there. And we found these white artifacts all through the exemplar up in the shaft space where it substantially could never

get. We found it all over the oil slingers, all over the bearings, everywhere. And even in the tube that we did have that screwed in the bottom that went in there, the artifacts of oil all in there.

Also -- I wish I had a picture to show you. In the overhaul shop, and there is a overhaul tag on it, someone used a very excessive amount of gasket sealer and it squeezed out all over the place. The vent location where the little tube goes in like this, it's a vent down here -- not a bunch of holes, it looks like a slot from the outside -- that was completely filled and covered with gasket sealer. It took me ten minutes of digging and pulling to get it out of there. So this particular ACM was in not very good shape and maybe why it was taken out of an airplane. I don't know.

Q. And you don't recall who you purchase this exemplar ACM from?

A. No. We have the tag where we bought it. I think the name started with a C. I just don't remember where it was.

Q. Do you know when --

A. I'll tell you where --

Q. I'm sorry.

A. It should be in some -- we sent -- I can't remember if we gave him the bill or not. Anyway, we have an invoice, we have something, I just don't know -- I can't remember the name.

MR. ODELL:

John, we'd like to request whatever records Mr. Hansen or his firm has about this exemplar ACM and where it came from.

BY MR. ODELL:

Q. Do you know when your exemplar ACM was last used in an aircraft?

A. I do not.

Q. You don't know whether it's been a month or ten years?

A. I do not know.

Q. Do you know when the exemplar ACM that you've got was last overhauled?

A. There's an overhaul tag on it. It's hard to read but it's there.

Q. Does it indicate who overhauled it?

A. It should.

Q. You don't recall?

A. No. I remember it's rolled up and I didn't want the destroy it. I just kind of -- I

could see a little bit but I just left it alone.

MR. ODELL:

We'd like the request either a copy of the overhaul tag that the witness has referenced or a photograph of it or the opportunity to inspect it.

MR. MITCHELL:

Okay.

BY MR. ODELL:

Q. Anything else in Mr. Dziorny's report?

A. Yes, and I'm still reading. Okay. With our -- on 25 he seems to be saying that you can't get anymore oil in there but 37 ccs inside this oil compartment. But inside the ACM, our little turbulence test indicates you definitely can.

On 26 and 27 paragraph numbers, he talks about the wicks system. And I think sort of implies that it's a -- sort of a state of the art, and it really is not. It was from the 1920s and I have a -- I think reference to some things I've seen that it's a bad idea to have high speed shafting to have wick oil system, no one does that really.

Q. No one does that today?
A. Probably for many years now.
Q. When did "they" stop doing that?
A. A few decades ago, I'm sure.
Q. And when was the design for the BUR-20 made, do you recall?
A. 1950 or '51. I think the patent I saw is dated '53 or '55, something like that. But that doesn't mean it can't be changed. The big problem with them is that fill material gets in the bearings and seals and makes them ineffective?
Q. Anything else in Mr. Dziorny's report?
A. Still reading. Oh, in 28 he talks about the vent system for it and I'm very well aware that industrial practice of high point vents and low point drains, known them all my life. The problem with this was the low quality drawings that we got were not the drawings that were dimensioned -- the drawings at all. They do not depict any sort of vent system at all. We had to buy the ACM exemplar. The drawings, I would say, were almost totally inadequate that were given.

Q. And did you buy the -- but you bought the ACM exemplar before you completed your report in the case, correct?

A. Yes, right.

Q. So you had the benefit of the exemplar at the time that you wrote the discussion that Mr. Dziorny wrote -- references in paragraph 28, correct?

A. Right. But if he had looked at his own drawings, the ones sent to us, he would see that there was no vent system depicted. But yet he says I should no better. Now, industrially, I certainly know better but it wasn't depicted on the drawings which raised a big question for us. Now, it's not quite so obvious for the ACM either because you can only take it apart so far.

Q. Anything else?

A. 30 and 31, he tells us there's only two ways oil can get in an inappropriate place. One is if it's sitting still, not working. The other one is if a bearing catastrophically fails in a fraction of a second. But he didn't declare which fraction, there's lots of fractions in a second. And if he would have probably just brought to zero speed and 32nd of a second, 16th

of a second, 10th of a second, probably destroy the whole thing. So he didn't -- he fails to mention a circumstance where a bearing is in process of failing and that's what usually always happens. Bearings aren't just perfect and all of a sudden just break. They deteriorate over time and cause vibrational issues.

And on 32 and 33 he talks about the air bearing problem and I think -- do you have that ASME referred to there?

Q. It should be attached to Exhibit 1, your report.

A. Okay. I think that's it right there. Can you find it?

Q. You've got it right there. I think it's PAI-9 to your report. In Exhibit 1, PAI-9 is the article about Foil Air/Gas Bearing Technology from the ASME. Is that it?

A. Oh -- oh, here it is right here, yes. Talked about it had to have a thrust runner and all this sort of stuff and if you look in that report on page seven, what drew my attention to is this rather small unit down here which does have a way to take up thrust but just not like the one above with what I would term a thrust

runner.

Q. Okay.

A. So my belief was that this could certainly be adapted somehow to an ACM and make it oil-less.

Q. But you haven't attempted drawing or a model doing that, adapting an air bearing to the existing BUR-20 ACM, correct?

A. Not other than looking at something. This will be the first preliminary -- all of my suggestions would be what someone would do if they were going to do something like that that would start but we haven't had any sufficient time to do any of those things about filters, sensors -- it's just very good suggestions and this is where I would tend to start right there.

Q. And so this is more in the nature of a suggestion than a tested, feasible alternative device, correct?

MR. MITCHELL:

Object to the form.

Mischaracterizes his testimony.

A. That's right. It's mischaracterized. These I think have -- I showed you. I believe have been tested like that but

their adaptation to the -- to take the place of this one, BUR-20, for example, I know of no one that's done that and I haven't done that either but I would only in process of starting such a thing.

BY MR. ODELL:

Q. And that was my question. I was asking about an actual adaptation of the Fairchild ACM, the BUR-20, that's type certificated for the Turbo Commander 690A aircraft. You have not tested and evaluated an alternative design of that ACM incorporating an air bearing, correct?

MR. MITCHELL:

Object to the form. Compound, tested and evaluated.

BY MR. ODELL:

Q. You have not tested or designed it, correct?

A. That's other than as far as I've gone here, that's right. I believe it would work based on what I read in the paper so that would take place of some testing at the moment, and design, at least I've got a picture of one that might very well work, but -- I was lucky to get

this report out as far as we went on time, so.

Q. Okay. Anything else in Mr. Dziorny's report that you disagree with or objected to?

A. Well, he says in 34 it'd be impossible to retrofit. I don't know -- the word impossible is a very big word, I don't think I would say that. I think probably it may not happen or it maybe well could happen.

Q. But you don't have an opinion as to whether it is feasible economically and technically to refit the Environmental Control System of a 690A aircraft with an air bearing ACM?

A. Sitting here today the answer is no.

Q. Okay. Anything else?

A. On 35 and 36 he says it's -- the ACM has not been subjected to airworthiness directives or complaints.

Q. Do you disagree with that?

A. Yes. The airworthiness directives found nothing but complaints, yes. Every time someone sends one in for overhaul they're complaining that it doesn't work. And --

Q. Well --

A. -- then at the last sentence down there he says that he reviewed Fairchild's records and revealed no such complaints. So you'd have to think, well, these records -- they've been making these things -- or they've been around for 66 years. Did he review those records? I don't believe he did.

Q. Why not?

A. I don't -- I just don't believe it.

Q. Do you have any reason -- do you have any indication that that's not true?

A. Well, he didn't say -- he didn't give any records. He just said he reviewed records. Which records? He didn't say anything about what they were. So I have no confidence that he did 66 years of records. And additionally, for the last 16 years these records have been I suppose in Maryland and I wonder if he went there and looked at any of those.

Now, I don't know what he means by complaint. I've called a complaint what I have defined it for you.

Q. What is it -- well, let me -- let's look at the actual language of his report. Okay? Paragraph 35, the second to last sentence says,

"To my knowledge, the Fairchild ACM has never been the subject of any airworthiness directive." You agree that is correct?

A. I didn't find any.

Q. The next sentence says, "Until it was served with this lawsuit, Fairchild had never received any complaints about bleed air contamination issues allegedly related to it's ACM." Do you have any facts indicating that that is untrue?

A. No facts because I don't have the records in front of me.

Q. Okay. You are not aware of any complaints communicated to Fairchild about bleed air contamination issue allegedly related to it's BUR-20 ACM, correct?

A. That's right.

MR. ODELL:

And Chris, I ask that y'all produce any records reviewed by Mr. Dziorny related to Fairchild complaints.

MR. ODELL:

We'll take it under advisement.

BY MR. ODELL:

Q. And paragraph 36 says, "Other than

the specific incident involving the Plaintiffs in this case, I am unaware of any other complaints about so called bleed air contamination involving a Fairchild ACM and a review of Fairchild's records revealed no such complaints." Have you ever seen any records containing complaints about so called bleed air contamination involving a Fairchild BUR-20 ACM other than this specific incident in this case?

A. No, because the records have not been produced.

Q. Well, do you know whether they've been requested?

A. I have no idea.

Q. Okay. Anything else in Mr. Dziorny's report?

A. Let me see. Still reading. Oh, at 37 he talks about -- he says the ACM itself was not designed as a filter or anything and that's -- I thought --

Q. You don't disagree with that?

A. Oh, no, but why is the -- I didn't say that. It just was a little silly I thought. In 40 years of experience as engineer that would not be feasible to incorporate a retrofitted

filtration sensor into the ACM. Well I didn't say into the ACM.

Q. You agree that it would not be feasible to do that?

A. Yeah, but he's misquoting me. He's thinking I say this and I didn't say that. I've been over this several times already. And on A and B and C and D he has this picture of a little bitty ACM and says, see here, you can't stuff all that stuff in here. Well I never said do that. I said equipment. I pointed out to you the drawing I had referenced in our report.

Q. Okay. Anything else?

A. 39 same comments as below. He said -- again, I wasn't trying to put filters and sensors into the ACM itself, so that wasn't it.

Okay. That's it. That's all I can remember at this moment.

Q. Okay. We have been through the expert reports of Matthew Lykins and Paul Dziorny and you've identified all of the issues you have with both of those, correct?

A. No, I didn't say --

MR. MITCHELL:

Object to form. Mischaracterized

his testimony.

THE WITNESS:

I didn't say all. That's a big word too. I made a quick read through and the stuff that came to mind. I said I may have more later I just don't right now.

BY MR. ODELL:

Q. Okay. As you sit here today in your deposition, you've identified all of the objections or disagreements you have with the two of them that you are aware of, correct?

A. Basically that I'm aware of by just quick reading and telling you the answers, that's the best I can do right now.

Q. And have you been asked to prepare or undertake any kind of a rebuttal report either to Mr. Dziorny or Mr. Lykens' reports?

A. No.

Q. Is there any remaining work that you've been asked to do in this case that you have not yet completed?

A. No.

MR. MITCHELL:

Object to form. Just to any extent it ask for what trial strategy we have may

have.

MR. ODELL:

I didn't ask about any of those things.

BY MR. ODELL:

Q. Mr. Hansen, that's all I've got for you this afternoon.

A. Okay.

Q. Thank you for your time.

A. You're welcome.

(DEPOSITION WAS CONCLUDED AT 3:02 P.M.)

WITNESS CERTIFICATE

I, DON HANSEN, do hereby certify that the foregoing testimony was given by me, and the transcription of said testimony, with corrections and/or changes, if any, is true and correct as given by me on the aforementioned date.

________________ __________________________

DATE SIGNED DON HANSEN

Signed with corrections as noted.

Signed with no corrections as noted.

DATE TAKEN: 3/22/16

REPORTER'S PAGE

I, CYNTHIA M. GRIJALVA, Certified Court Reporter, in and for the State of Louisiana, the officer before whom this sworn testimony was taken, do hereby state:

That due to the spontaneous discourse of this proceeding, where necessary, dashes (--) have been used to indicate pauses, changes in thought, and/or talkovers; that same is the proper method for a Court Reporter's transcription of a proceeding, and that dashes (--) do not indicate that words or phrases have been left out of this transcript;

That any words and/or names which could not be verified through reference material have been denoted with the phrase "(phonetically spelled)."

CYNTHIA M. GRIJALVA, CCR, RPR

CERTIFIED COURT REPORTER

REPORTER'S CERTIFICATE

This certification is valid only for a transcript accompanied by my original signature and original seal on this page.

I, CYNTHIA M. GRIJALVA, Certified Court Reporter, in and for the State of Louisiana, as the officer before whom this testimony was taken, do hereby certify that DON HANSEN, after having been duly sworn by me upon authority of R.S. 37:2554, did testify as hereinbefore set forth in the foregoing 158 pages.

That this testimony was reported by me in the stenotype reporting method, was prepared and transcribed by me or under my personal direction and supervision, and is a true and correct transcript to the best of my ability and understanding.

That the transcript has been prepared in compliance with transcript format guidelines required by statute or by rules of the board, that I have acted in compliance with the prohibition on contractual relationships, as defined by Louisiana Code of Civil Procedure

Article 1434 and in rules and advisory opinions of the board.

That I am not related to counsel or to the parties herein, nor am I otherwise interested in the outcome of this matter.

CYNTHIA M. GRIJALVA, CCR, RPR
CERTIFIED COURT REPORTER

Expert Report / Review of
In-Flight Cabin Fume-Air Incident

Privileged and Confidential Subject to Attorney/Client Privilege

Prepared By

Don Hansen, M.E., P.E

PAI® Engineering (PAI)
A Licensed Texas Engineering Firm
11815 Justice Avenue
Baton Rouge, LA 70816

Under the direct supervision of:

STATE OF TEXAS
LEROY J. BLANCHARD III
109371
LICENSED
PROFESSIONAL ENGINEER

Leroy Blanchard, M.E., P.E.

Prepared For:

deGravelles, Palmintier, Holthaus, and Fruge', L.L.P.
618 Main Street
Baton Rouge, Louisiana 70801-1910

Attention: Mr. Michael C Palmintier

Mr. Michael C. Palmintier, Attorney-at-Law
deGravelles, Palmintier, Holthaus, and Fruge'
618 Main Street
Baton Rouge, Louisiana 70801-1910

Phone: 225 344 3735

Dear Mr. Palmintier:

RE: PAI Project: DPHF1402
USDC – Southern District
Case No: 4:15-CV-00827

The following pages are PAI Engineering's Expert Report of a 2011, May 31st incident in a Commander 690A Aircraft with FAA registration number N690EH. We have been asked to provide engineering analyses and opinions on certain facets of this incident after review of the subject case materials that we have.

The right is reserved to supplement this work upon receiving new information as it becomes available.

If additional detail or clarification is needed, please contact us at your convenience.

Very truly yours,

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PIPING ANALYSIS INCORPORATED™
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D. E. Hansen

STATE OF LOUISIANA
D. E. HANSEN
REG. No. 12592
REGISTERED
PROFESSIONAL
ENGINEER
IN
MECHANICAL ENGINEERING

Don Hansen, M.E., P.E

Figure 1- Exemplar Fairchild ACM refrigeration unit photo.
The design drawings appear to have a 1951 date (Bates Fairchild_00000040).

Background – For a period of about 1-1/2 hours, on 2011, May 31st, plaintiffs Mr. Kenneth Davidson and Mr. Thomas Farmer were reportedly exposed to toxic fumes (a fume event) while aboard the subject in-flight Turbo Commander 690A aircraft with FAA registration number N690EH. The design of this pressurized cabin aircraft allowed for high altitude operations such that the cabin environmental conditions of temperature, pressure, and overall air quality were suitable for human breathing.

- The exposures to Mr. Davidson and Mr. Farmer (the plaintiffs) occurred while aboard the subject aircraft which was being reasonably used for its intended purpose. These toxic fumes (fume is defined as a gas, smoke or vapor that smells strongly or is dangerous to inhale) include dangerous neurotoxins, reportedly from aerosolized and/or vaporizing turbine lubricating oils that leaked from the aircraft's engines and/or cabin environmental air control accessory components. The air control component at issue is the installed Fairchild Air Cycle Machine, ACM model BUR-20, being used during the flight.
- The toxic fumes entered the occupied confined space of the aircraft cabin though the air delivery system and duct system intended to condition (modify) the cabin environment: The subject Commander 690-A environmental cabin air system normally operates to pressurize, heat, cool, and partially dehumidify breathable cabin air through the use of pressurized unfiltered high pressure hot turbine engine compressor "bleed air" plus cooler "ram air" from outside the aircraft's airframe. Turbine engine "bleed air" typically reaches a temperature of about 300F at about 30 psig. The hot "bleed air" is throttled and then cooled with cooler outside "ram air" by a heat exchanger. Conditioned air is then introduced into the aircraft's cabin after passing through an Air Cycle Machine (ACM), in this case a Fairchild part number 977018-1 *(ref. doc. PAI-1a)*. The aircraft engines and the ACM are lubricated with BP2380 jet engine oil *(ref. doc. PAI-2a)*.

  One of the constituents of turbine engine oil is Tricresyl Phosphate (TCP). Aerosolized and/or vaporized sufficiently, turbine engine oil will fume, thus becoming a likely causative for short-and long-term ill health effects known since the year 2000 as Aerotoxic Syndrome[1] *(ref. doc. PAI-6c)*. None of these turbine oil constituents are intended to benefit human breathing ... they are a benefit only to the lubrication task for which they are designed: A leaking oil lubricated bearing seal allows some amount of engine oil to be pressured into the air stream that eventually finds its way into the occupied confined space of the aircraft cabin *(ref. doc. PAI-3)*. Once aerosolized and/or vaporized via heat and pressure effects, these oils can cause a fume event exhibiting an odor like frying pan fumes that can be visually and olfactorily detected as mist and/or smoke inside the aircraft cabin.

[1] Balouet, J.C., Winder, C. New Orleans ASTM Symposium on Air Quality in A/C Cabins, p. 27-28, 1999, October

- On 2011, May 31st, at about 28,000 feet, the aircraft experienced a major fume event, emitting clouds of odorous oil fumes into the cabin. Mr. Farmer contacted Air Traffic Control, aborted the mission and initiated a rapid decent to depressurize the aircraft. Mr. Farmer was subsequently able to safely land the aircraft. The plaintiffs allege, on information and belief, that drops of the engine's lubrication oil were leaking out of the aircraft's engine into the bleed air-ducting system, which caused the cabin of the aircraft to fill with fumes *(ref. doc. PAI-12a)*. The plaintiff's belief can, more likely than not, also include oil leakage from the oil lubricated ACM as another and more voluminous source.
- Commander N690EH contained, as part of the cabin environmental control system, an ACM model BUR-20 designed by Fairchild, part number 977018-1. It is most likely that damage-causing dangerous fumes, generated from aerosolized and/or vaporized turbine engine oils, were allowed to enter the cabin through the use of the ACM at issue. These fumes entered the confined space of the aircraft's cabin unimpeded and unidentified until it was too late to avoid the damages to each of the plaintiffs. The documents that we have show no safety features such as oil-less bearings, fume absorbers, filters, or early warning sensors that could have operated to avoid damage to cabin occupants.

The incident aircraft, a Turbo Commander aircraft bearing FAA registration number N690EH, was not safe to operate under normal conditions on the date of the incident because of aerosolized and/or vaporized turbine engine oils from:

1. Leaking aircraft engine oil seals entering the cabin through the ACM, and
2. Leaking oil seals within the Fairchild ACM

Based upon the above, it is my professional opinion that the root cause for the toxic atmosphere within the confined space of the aircraft's cabin (and the injuries to plaintiffs) was due to exposing cabin occupants to turbine engine oils, oils that became aerosolized and/or vaporized fumes. These oils, containing constituents such as Tricresyl Phosphate, resulted in a dangerously polluted breathing environment within the confined space of the aircraft's cabin *(ref. doc. PAI-1, PAI-6, & PAI-10)*.

Discussion:

The ACM's condition deviated in a material way from available safety specifications & standards:

Occupational Health and Safety Standards such as 29CFR1910.146(b) *(ref. doc. PAI-4)* limit the amount of chemicals within a breathable working environment, an environment that can be tested and sensed for dangerous substances. The OSHA standard 1910.1000 Table Z-1 *(ref. doc. PAI-5)* states the long-term permissible exposure limit[2] is 0.1 mg/m^3 for the neurotoxin Triorthocresyl Phosphate (ToCP, an isomer[3] portion of TCP). According to EH40/2005 Workplace exposure limits *(ref. doc. PAI-13)*, the short-term total weight average permissible exposure limit of ToCP is 0.3 mg/m^3. The estimated ToCP concentration in a cabin during a fume event in which aerosolized and/or vaporized liquid can be seen is 0.5 mg/m^3 *(ref. doc. PAI-6a)*.
According to our calculations performed in Exhibit A, page 11, approximately 1.085 drops of aerosolized turbine oil dispersed throughout the entire cabin of the Twin Commander 690A surpasses the OSHA long-term 8 hour permissible exposure limit and 3.2415 drops surpasses the short-term 15 minute exposure limit. There are no sensors suggested for, or provided with, the ACM to detect engine oil fumes before they became dangerous to the plaintiffs. Moreover, there is no instruction or mechanism to timely and safely bypass or divert fumed airflows coming from the ACM. Unfortunately, the only way for "clean" outside air to arrive within the cabin is through the Fairchild ACM *(Bates # CD03832 & 384747 & PAI-12c)*, and this airway has no filters or absorbers. The ACM leaking less than one drop of oil per minute would continuously and thoroughly pollute the aircraft's cabin:

[2] The long-term and short-term total weight average permissible exposure limits are the levels of exposure established as the highest level of exposure an employee may be exposed to without incurring the risk of adverse health effects over a period of 8 hours, and a period of 15 minutes, respectively.
[3] An isomer is a molecule with the same chemical formula as another molecule, but a different chemical structure. The ToCP isomer typically makes up 33% of TCP in engine oil *(ref. doc. PAI-6b)*.

Federal Air Regulation FAR-25 requires at least 0.55 lbm/minute/cabin occupant of outside make-up ventilation air *(ref. doc. PAI-10a)*, which is the cabin air change rate to ensure 0.127 lbm/minute/occupant O_2. The primary reason for the large volume of make-up air at altitude is to maintain O_2 partial pressure for aviator/occupant lung function, not to account for the small volume taken in/out by an occupant's lungs at about 0.007 lbm/minute of O_2 (*ref. doc. PAI-7 & PAI-10a*). It appears that the N690EH environmental system is designed for one air change about every five minutes, and to maintain cabin pressure altitude at 8000 feet msl (measured from sea level) = 5.2 psi while flown at 23,900 feet msl (Exhibit A, page 12).

Air changes have little effect on removing infused pollutants from the aircraft's interior materials *(ref. doc. PAI-12b)*. Making matters worse, the Personal Exposure Limit (PEL) for toleration of pollutants are reduced at higher cabin altitudes *(ref. doc. PAI-11)*.

The aircraft maintenance manual, (*Bates # CD03505-CD04253*) provides no instruction for a pilot or aviation mechanic to see if excess turbine oil resides within the Fairchild ACM prior to any flight or intention of flight: The only ACM pre-flight check is to *"inspect the refrigeration unit oil filler and maintain oil level at top of filler neck"*, a process that only adds oil into the ACM (*ref. doc. PAI-7a*) without an easy way to check if too much oil resides inside the ACM. Fairchild drawings call for a filler / drain fitting (Bates# Fairchild_00000040). Ostensibly, this fitting should be able to empty the low point oil sump, but no drawings or representations are available to describe how to drain oil, to measure added oil, and thus render safe the exact quantity of oil in the ACM sump. There is no drawing to depict or exactly locate the *"oil filler valve assembly, installed on a bracket attached to the top left side of the refrigeration unit"*, a location that would provide an oil level higher than the top of the oil wick *(ref. doc. PAI-7b)* and thus over-oil the wick/shaft housing space.

For testing, Fairchild requires exactly 37cc (0.078 pint) of oil (Bates # Fairchild_00000052 & 54), implying that some exact small amount of oil is required for normal operations.

The maintenance manual offers a solution to eliminate and prevent noxious fumes from entering the cabin from the engine bleed air by isolating the problematic engines bleed air, but has no mechanism or instruction to divert or isolate contaminated air leaving the ACM *(ref. doc. PAI-7e)*. The manual also fails to list a fume event warning in the three page Troubleshooting section Fig. 9-14 *(ref. doc. PAI-7c)*, thus ignoring well known Aerotoxic Syndrome issues.

Additionally, there is no way for a pilot or aviation mechanic to determine the effectiveness or operating state of the hidden ACM's oil seals. The only way to determine the effectiveness of these important items is to send the ACM in for overhaul by Fairchild, a process that nearly guarantees a fume event: Both the original ACM and the overhauled ACM (*Serial #0335*) had evidence of oil leakage from the turbine side and the impeller side of the rotor (*ref. doc. PAI-8*) thus indicating ACM oil seal leakage.

An available safety solution would have been for Fairchild to retrofit the design to use industry common oil-less bearings within this Fairchild ACM to avoid the toxic fumes that entered the confined space of the aircraft as described in the paragraphs below.

Alternative systems capable of preventing the claimant's damage (which would not be unduly burdensome on anyone) were/are available – Modern design practices for ACM equipment avoids the use of turbine engine oil lubrication systems entirely, instead using "air bearings" *(ref. doc. PAI-9)* and "ceramic hybrid bearings". Additionally, high efficiency particulate (HEPA) filters combined with activated charcoal or similar filters could have been installed to remove both particles and chemicals from the cabin air *(ref. doc. PAI-10b)*. In the interest of safety, Fairchild could and should have produced some FAA Supplemental Type Certificate (STC) to at least install some fume sensors, filters, absorbers, and/or suggested diverters to adequately warn cabin occupants such as the plaintiffs. Also, Fairchild could have used oil-less bearings as suggested above.

a

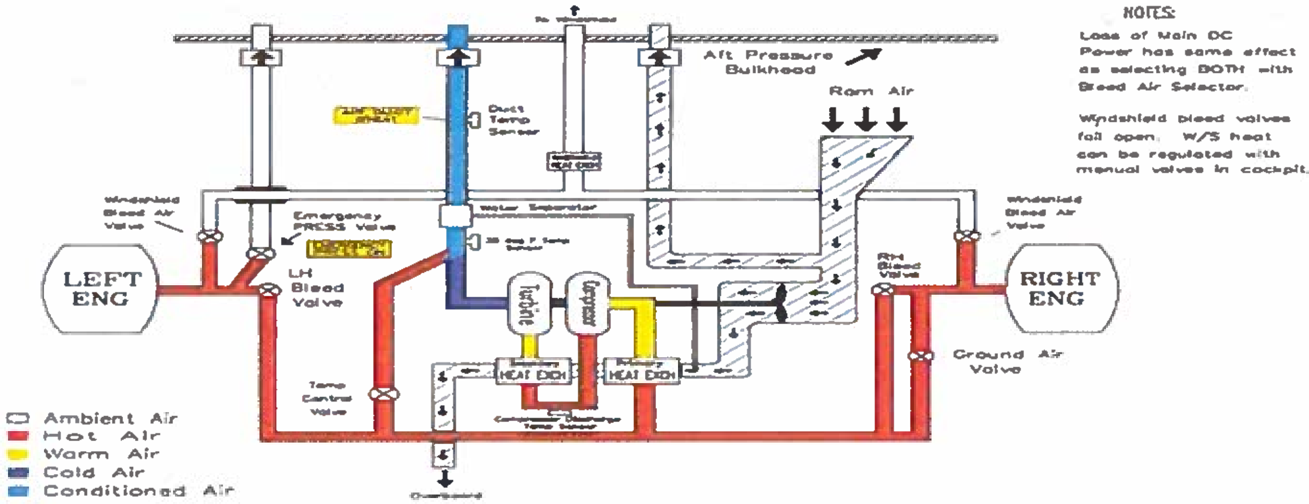


Figure 2 – Example Mechanical Flow Diagram for a Common ACM System

The aircraft's ACM possessed unsafe weakened characteristics that caused injury and damage. The various aircraft users may not have had reasonable or adequate warning of such unsafe characteristics and the dangers to the plaintiffs: Worn / leaking oils seals are all that separated the health of anyone inside the confined space of this aircraft's cabin from the effects of dangerous turbine engine oil fumes, fumes that are known to cause impairments to human health and wellbeing. Two possible sources of oil that can be mixed with the air that goes into the cabin are seen in the example air flow diagram in Figure 2: The "bleed" air and the ACM. The hot "bleed" air leaving the engines contains oil particles because Garrett Engines normally leak *(ref. doc. PAI-1b)*. The ACM Compressor/Turbine also requires oil for the bearings (unless the better oil-less bearing system were used), which could leak into the airflow. This air would then leave the ACM and enter the cabin to be inhaled by cabin occupants.

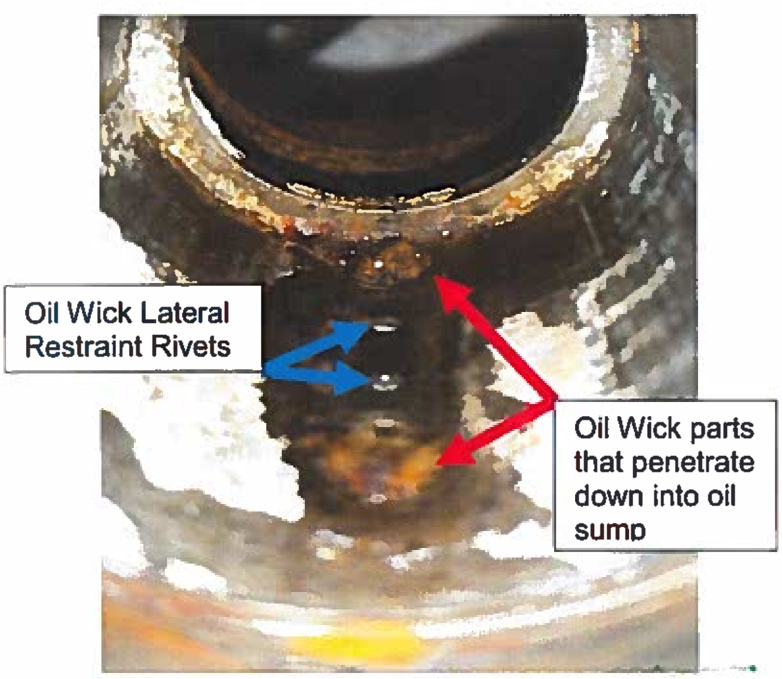


Figure 3 – Oil Wicks and Rivets

Figure 4 – Wick restraint and portion of wick that contacts shaft

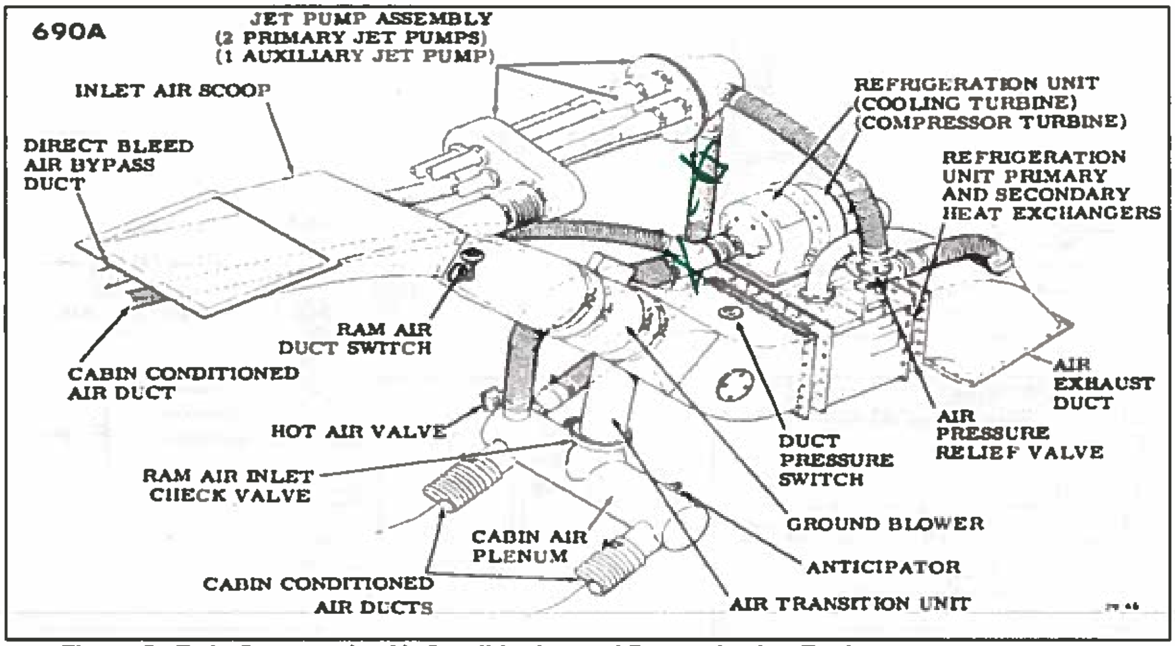


Figure 5 - Twin Commander Air Conditioning and Pressurization Equipment ***(Bates # CD03832)***

The Twin Commander 690A's ACM contains an unknown small amount of oil ("less than a pint") in an oil wick/filler system to lubricate two bearings and seals within the 36,000 rpm ACM compressor *(ref. doc. PAI-2b)*. If any of this oil were to leak out of this "wick" system (contained within the "Refrigeration Unit" depicted in Figure 5 above and seen in Figure 1 on page 3), it would leak into the airflow that would be released into the cabin (see airflow diagram in Figure 6). If an air particle/fume detection system were in the ACM or airplane cabin, the pilot might be timely warned of the oil particles in the ACM or bleed air, and could then take the necessary steps to avoid breathing in the oil fumes and neurotoxins in the contaminated air. Such commonly used early detection technology would minimize or completely eliminate the chances of injury due to the inhalation of contaminated cabin air…so long as there was some viable way to breathe clean air.

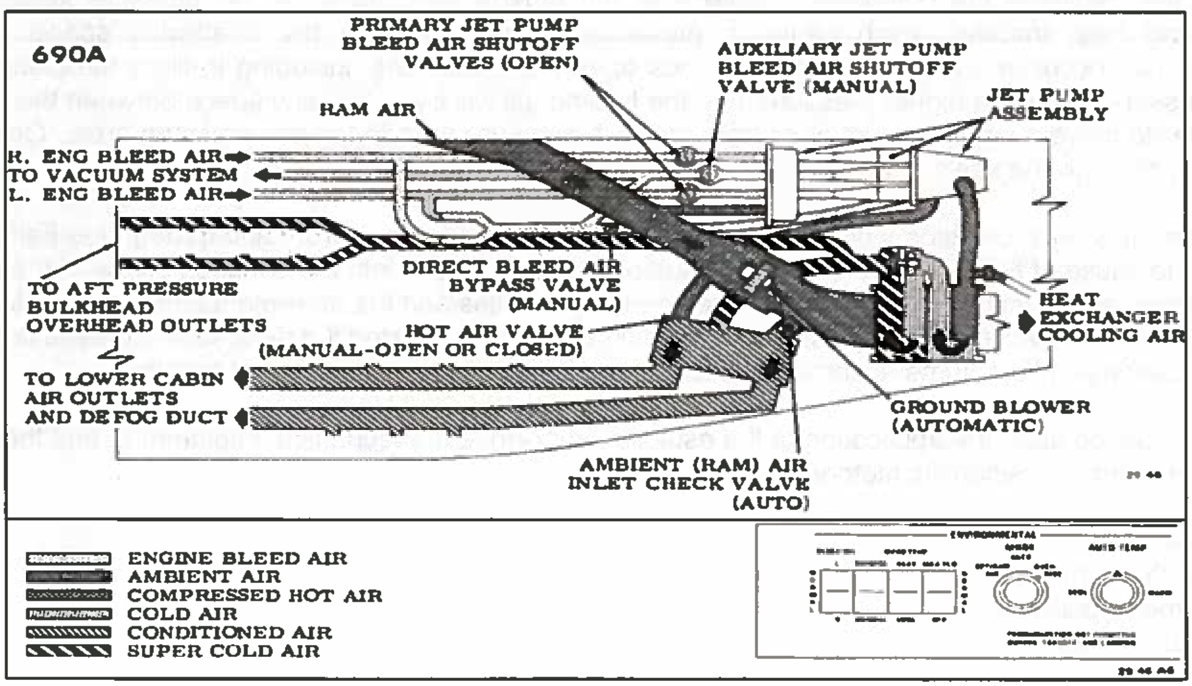
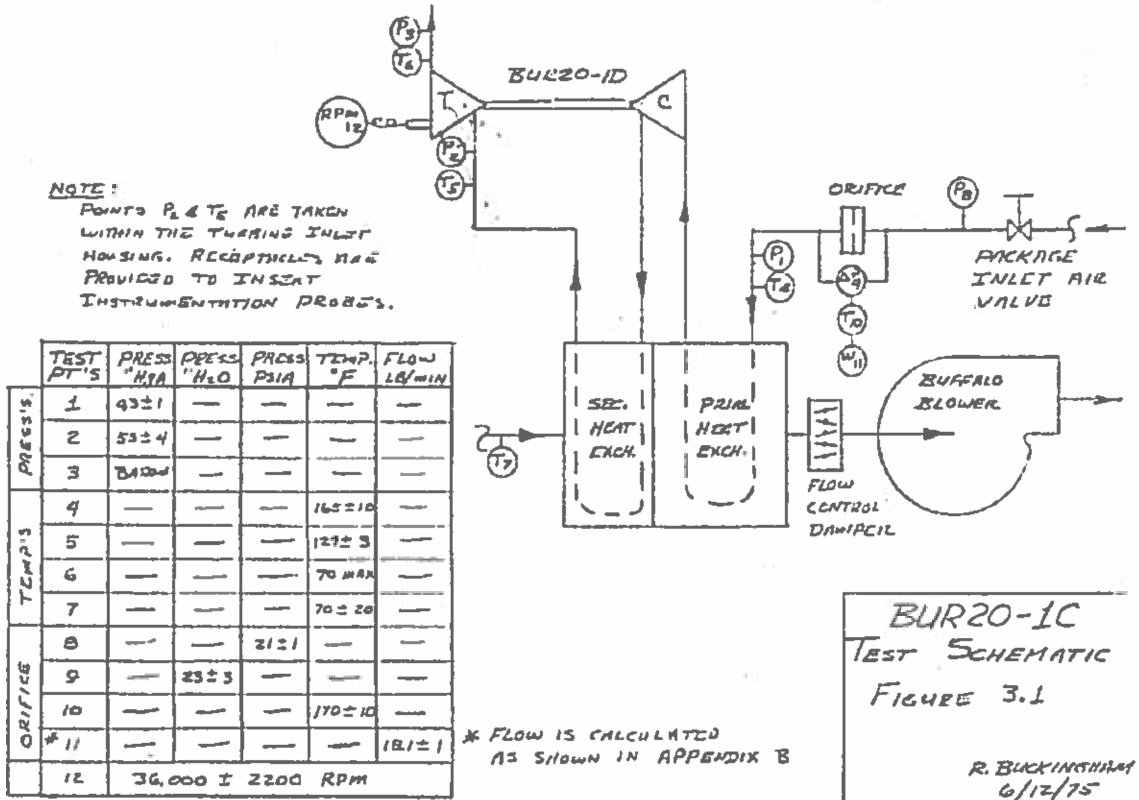


Figure 6 – Override (Manual) Condition Air Flow Diagram ***(Bates # CD03847)***



	TEST PT'S	PRESS "HGA	PRESS "H2O	PRESS PSIA	TEMP. °F	FLOW LB/MIN
PRESS'S.	1	43±1	—	—	—	—
	2	53±4	—	—	—	—
	3	BAROM	—	—	—	—
TEMP'S	4	—	—	—	165±10	—
	5	—	—	—	127±3	—
	6	—	—	—	70 MAX	—
	7	—	—	—	70±20	—
ORIFICE	8	—	—	31±1	—	—
	9	—	23±3	—	—	—
	10	—	—	—	170±10	—
	*11	—	—	—	—	18.1±1
	12	36,000 ± 2200 RPM				

Figure 7 – Fairchild ACM Testing Diagram ***(Bates # FAIRCHILD_00000051)***

How ACM lubrication oil was forced into the aircraft cockpit:

Fairchild's ACM testing diagram (Figure 7, above) shows a graphic representation of the testing equipment setup. When the air comes out of the compressor, it goes through some tubing and through a heat exchanger leading to the turbine. Between the compressor outlet and the turbine inlet, there will be pressure losses due to viscosity and heat transfer which cause a pressure differential within the shaft/wick space. Pressure differentials can occur in either direction at various operating conditions, including in-flight turbulence. Since the compressor can have a higher pressure than the turbine, oil will try to find any space between the shaft and seal in order to move a small amount of oil from the high pressure area to the low pressure area. Once the oil finds its way through the seals, it will force itself into the air going into the cabin.

Conclusion: It is my professional opinion that leakage of turbine engine oil from and through the Fairchild ACM was the cause of the observed and dangerous oil fume emissions into the confined space of the cabin: This opinion is based upon the use of sound engineering principles and the aforementioned review. Moreover, the exposure to the toxic jet engine oil should and could have been avoided if defendants had used common oil-less air bearings, filters, fume absorbers, sensors, or other easily available design features.

Our report is based upon the application of the established science of mechanical engineering and the Galambosian four step scientific method:

1. Observation
2. Hypothesis Formulation
3. Extend the Hypothesis
4. Observation Again

The right is reserved to supplement this work upon receiving new information.

If additional detail or clarification is needed, please contact me at your convenience.

Very truly yours,

PAI ENGINEERING
PIPING ANALYSIS INCORPORATED

Louisiana Engineering Firm License No. EF-647
Texas Engineering Firm License No. 12934

Don Hansen

Don Hansen, M.E., P.E.

Case Documents Reviewed –

- Depositions of John Probst (9/5/2012), Kenneth Davidson (6/7/2012), Dr. Christiaan Van Netten (10/15/2012), Dr. Robert Harrison (8/24/2012) and Thomas Farmer (6/7/2012 & 1/25/2013)
- NCG 1 – Materials from John Probst
- Northrop Grumman maintenance records
- Bates Document #s: FAIRCHILD_00000001 - FAIRCHILD_00000063, EC 000001 - EC 000660, CD00180 -CD04326, & HON-0000001 - HON-0002799
- Original Complaint from Plaintiffs (5/30/2014 New York, New York)
- Ramsden, Jeremy J. Jet engine oil consumption as a surrogate for measuring chemical contamination in aircraft cabin air, *Journal of Biological Physics and Chemistry* Vol.13 (2013) 114-118
- Carpe Diem, Eagle Creek, Twin Commander, AlliedSignal, Honeywell, & Fairchild Controls: Initial Disclosures
- Carpe Diem, Eagle Creek, Twin Commander, AlliedSignal, Honeywell, Fairchild Controls, & Standard Aero: Responses to Request for Proposals
- Twin Commander: Responses to Request for Documents & Answers to First Interrogatories
- Occupational Safety and Health Administration (OSHA) 1910.146(b) and 1910.1000 Table Z-1 Standards
- *EH40/2005 Workplace exposure limits*
- *Foil Air/Gas Bearing Technology ~ An Overview:* ASME Publication 97-GT-347
- *Air Quality in Airplane Cabins and Other Similar Enclosed Spaces, Volume 4*
- Gorla, Rama, and Aijaz Kahn. *Turbomachinery Design and Theory* (2003).

PAI Reference Document List

PAI-1: Probst Airframe Logbook Entries dated 2011, June 24th and 2011, August 1st ; Bates #s HON-0000014, HON-0000629, and HON-0000630 (States that Fairchild was the ACM manufacturer, gives the P/N designated for the ACM, and gives tables of allowable engine fluid leakage)

PAI-2: John F. Probst deposition dated 2012, September 5th, 20:14-21:7 (States the turbine and ACM oil used are BP 2380)

PAI-3: Gulfstream Commander 690A/690B Maintenance Manual figures 4-5, 8-2, 9-2 and 9-8 (Shows the path oil particles could take from the engine to the cabin air ducts)

PAI-4: OSHA standards 1910.146(b) (States the environmental conditions needed for a confined space to be safe)

PAI-5: OSHA standard 1910.1000 Table Z-1 (Lists permissible exposure limit of TOCP)

PAI-6: Ramsden, Jeremy J., Jet engine oil consumption as a surrogate for measuring chemical contamination in aircraft cabin air, Journal of Biological Physics and Chemistry Vol.13 (2013) 114-118 (Gives calculations of oil, TCP and TOCP concentrations that would be present in a cabin during a fume event)

PAI-7: Twin Commander Maintenance Manual excerpts

PAI-8: John F. Probst Deposition Page 166

PAI-9: Foil Air/Gas Bearing Technology ~ An Overview: ASME Publication 97-GT-347

PAI-10: *Air Quality in Airplane Cabins and Other Similar Enclosed Spaces, Volume 4,* pages 73-74. ISSN 1433-6855

PAI-11: Dr. Christiaan Van Netten deposition 2012, October 15th, pages 66 thru 67.

PAI-12: Mr. Thomas Farmer's deposition of 2012, June 7th, pages 5 thru 11.

PAI-13: EH40/2005 Workplace exposure limits

This Report Exhibit "A" – Critical concentration of engine oil in the cockpit at a given time

An approximation of the volume of the cabin that would be affected by a fume event can be calculated from figure 1-1 of the aircraft maintenance manual *(ref. doc. PAI-7d)*. The length of the cabin is from station 12.5 inches to station 172.5 inches, which results in a length of 160 inches. The height of the cabin goes from station -65.0 inches to station 2.0 inches which gives a height of 67 inches. The distance from the centerline of the cabin to the outside station to the edge is 24.07 inches. Multiply this times 2 to get a cabin width of 48.14 inches. Assuming an empty rectangular prism (a generous approximation), the length * height * width will give an approximate volume.

$$Cabin\ Volume = 160\ in\ * 67\ in * 48\ in = 514560\ in^3 = 297\ ft^3$$

$$Cabin\ Volume = 514560\ in^3 * \frac{1\ m^3}{61023.7\ in^3} = 8.432\ m^3$$

The OSHA long-term total weight average permissible exposure limit of ToCP is 0.1 mg/m³. Therefore, the OSHA critical mass of ToCP in the cabin at a given time is calculable.

$$M_{critical\ ToCP} = 8.432\ m^3 * 0.1\frac{mg}{m^3} = 0.843\ mg$$

With a mass ratio of TCP to ToCP or 3:1 *(ref. doc. PAI-6b)*, this gives a critical mass of TCP to be:

$$M_{critical\ TCP} = 0.843\ mg * 3 = 2.529\ mg$$

TCP has a density of 1170 mg/cm³ *(ref. doc. PAI-6d)*, so the critical volume of TCP in the cabin can be derived:

$$V_{critical\ TCP} = \frac{2.529\ mg}{1170\ mg/cm^3} = 0.002162\ cm^3$$

The composition of turbine oil typically has a 3% TCP makeup *(ref. doc. PAI-6e)*. This percentage can be used to calculate the total critical volume of oil allowed in the cabin.

$$V_{critical\ oil} = \frac{0.002162 cm^3}{.03} = 0.07207\ cm^3$$

Since a drop of oil is considered to be 0.0667 cm³ (15 drops = 1 cm³ *(ref. doc. PAI-1b)*), the critical amount of drops of fumed and/or aerosolized oil in the cabin is:

$$Critical\ drops\ of\ oil = \frac{0.07207 cm^3}{0.0667\ cm^3} = 1.0805\ drops$$

According to EH40/2005 Workplace exposure limits *(ref. doc. PAI-13)*, the short-term total weight average permissible exposure limit of ToCP is 0.3 mg/m³. This limit shares the same principle as the 8 hour long-term limit, but uses a 15 minute exposure limit rather than 8 hours. This ToCP exposure limit is three times higher than the OSHA long-term limit, so the short-term super critical number of drops of oil will be three times higher than the critical OSHA amount.

$$Super\ critical\ drops\ of\ oil = 1.0805\ drops * 3 = 3.2415\ drops$$

Given that the plaintiffs claim to have been exposed to the fumes for approximately 1.5 hours, the total amount of oil in the cabin at any given time that would be considered dangerous to their health would fall in the range of 1.0805 drops to 3.2415 drops.

The oil could possibly be in aerosolized form due to the high rpm of the blades within the ACM, which would sling the oil at a high velocity, separating the oil drops into a fine mist. The oil could also be in the form of smoke due to the high temperatures of the bleed air leaving the engines. This bleed air could possibly have a temperature higher than the flash point of 265°C for BP Turbo Oil 2380, or the boiling point of 255°C for TCP. These 1.0805 to 3.2415 drops of oil can be in the form of smoke and/or aerosolized, because the regardless of the physical form that the 1.0805 to 3.2415 drops of oil takes up, the mass of ToCP within those drops of oil is mostly constant.

Another factor that must be taken into account is the constant flow of air into and out of the cabin. The twin commander 690A is designed to carry 2 pilots and 6 passengers, so the aircrafts cabin air change rate should be designed to accommodate 8 people. Federal Air Regulation FAR-25 requires at least 0.55 lbm/minute/cabin occupant of outside make-up air *(ref. doc. PAI-10)*. The total required air change rate can therefore be calculated:

$$FAR-25\ cabin\ air\ change\ rate\ =\ 0.55\frac{lbm}{minute}*8\ cabin\ occupants\ =\ 4.40\ \frac{lbm}{minute}$$

Using the cabin volume of 297 ft^3 calculated above, and the density of dry air at standard conditions of 0.075 lbm/ ft^3, the mass of the total air in the cabin can be calculated.

$$Mass\ of\ cabin\ air\ =\ 297\ ft^3*0.075\ \frac{lbm}{ft^3}\ =\ 22.275\ lbm$$

The FAR-25 required amount of air changes per minute for the Twin Commander 690A can be calculated by dividing the total mass of cabin air by the required air change rate.

$$Required\ air\ change\ rate\ =\frac{4.40\ \frac{lbm}{minute}}{22.275\ lbm}=0.198\ \frac{air\ changes}{minute}=11.85\ \frac{air\ changes}{hour}$$

This air change rate falls within the "normally adequate" range of 10-15 air changes per hour outlined in *Air Quality in Airplane Cabins and Other Similar Enclosed Spaces* *(ref. doc. PAI-10c)*.

The critical and super critical oil leakage rate are equal to the air change rate multiplied by the critical and super critical drops of oil.

$$Critical\ oil\ leakage\ rate=1.0805\ drops*0.198\ \frac{air\ changes}{minute}=0.214\ \frac{oil\ drops}{minute}=12.84\ \frac{oil\ drops}{hour}$$

$$Super\ critical\ oil\ leakage\ rate=3.2415\ drops*0.198\ \frac{air\ changes}{minute}=0.642\ \frac{oil\ drops}{minute}=38.51\ \frac{oil\ drops}{hour}$$

Using these rates, the ACM leaking between 0.214 and 0.642 drops of oil per minute would continuously and thoroughly pollute the aircraft's cabin with enough ToCP to likely incur the risk of adverse health effects.

-----END-----

Curriculum Vitae D. E. Hansen, M.E., P.E.., President PAI Engineering

Mr. Hansen specializes in Computational Fluid Dynamics, Finite Element Analysis for stresses and heat transfer, generalized stress, flow and dynamic analysis for piping systems, engines, turbo machinery, pumps, vessels, and related structures, and aircraft engines and airframes. He is a mechanical engineer with graduate work in engineering mechanics, physics, and advanced physics. He is a licensed/registered engineer in Louisiana, Oklahoma, Utah, Trinidad-Tobago, and Florida, and holds FAA licensure as an airframe & power plant mechanic and commercial instrument multi-engine rated pilot.

EDUCATION: Bachelor of Science in Mechanical Engineering; 1966 Louisiana Tech University
Post-Graduate Work in Engineering Mechanics, Physics, and Advanced Physics
Louisiana State University and the Liberal Institute of Science and Technology

EXPERIENCE: Mr. Hansen worked as a mechanical engineer at Tenneco from 1966-1967. He also worked Ethyl Corporation from 1967-1977, serving as co-ordinator of engineering projects in charge of design, project engineering, and construction activities.
Mr. Hansen founded PAI Engineering in 1972. As president and chief mechanical engineer of PAI Engineering since 1972, Mr. Hansen has authored several large-scale computer programs to solve stress analysis and flow problems, and structural and vessel problems. These programs provide optimization of mechanical systems to produce quality solutions. PAI provides competent engineering assistance to engineering, legal, and maintenance organizations throughout the world through the use of unique and comprehensive computer programs and methods of solution. Successful solutions are produced for difficult problems with rotating machines such as gas expanders, turbines, engines, aircraft engines, compressors, pumps, and fixed equipment such as heat exchanges, aircraft airframes, and vessels. The results of PAI's work are presently operating throughout the Americas, Europe, and Africa.
Mr. Hansen has also taught courses in the Engineering Department at Louisiana State University from 1970-1972.

AFFILIATIONS: ASME 1970 to present AIChE 1980 to present

PUBLICATIONS / PAPERS / PRESENTATIONS
"Boiler and Machinery Protection through Control of Piping Reactions" Presentation and Paper at Loss Prevention Symposium 1986

"Control Mechanical Reactions in Piping" Article in Chemical Engineering Progress

"Piping Overloads - Topping Turbines" AIChE Ammonia Symposium. Presentation and Paper 1990

"Piping Reactions" Ammonia Symposium. Presentation and Paper 1991

"Piping Overloads" Ammonia Safety Symposium. Presentation and Paper 1998

"Pressure Relief Valve Piping Failures and Fire: Ammonia Synthesis Loop" AIChE Presentation and Paper 1999

"Consideration of Fatigue Life in the Design of Vessels in Molecular Sieve Dryer Service" AIChE Annual Safety Symposium 2003

Several Articles in "Plant/Operations Progress"

RATE OF COMPENSATION
Principal Engineer Project Direction and Solutions US$275.00/Hour
Project Engineer Project Co-ordination US$235.00/Hour
Metallurgical Engineer Metallurgical Investigation US$295.00/Hour
Design Engineer Mechanical/Structural Design US$225.00/Hour
Senior Designer Layouts, checking, design US$215.00/Hour
Designer Design, drawings, details US$189.00/Hour
Drafter Drawings, details US$183.00/Hour
Support Secretarial, reproduction US$177.00/Hour
Program Usage Proprietary Analysis Programs N/C

Legal and Forensic Cases

JOB NO.	CASE	DESCRIPTION	LAW FIRM/COMPANY
BDP1201	CNRL v. ShawCor Ltd., IMV Projects Inc., & Flint Field Services Ltd.	Underground Pipeline Insulation Failure; Alberta; Consultant, Expert Report	Burnet, Duckworth & Palmer, LLP Canada
BRNY1301		Drill Pipe Failure	Briney Foret Corry, Attorneys Lafayette, LA
BRUN0401	Mississippi Chemical Vessel v. Plant Maintenance Services	Court of Yazoo City, MS; Consulant	Brunini, Grantham, Grower & Hewes, PLLC; Jackson, MS
CBY1501	Hanson Pressure Pipe, Inc. v. Delta Steel, Inc.	Piping Spec. Inspection & Verification; Field Investigation	Cokinos, Bosien & Young Texas
CFW1401	Haile v. Wise Choice Invest., Sebron Neil Wise, & Charter Oak Fire Insur. Company	Injury at O'Neal Gas Bulk Facility	Clayton, Fruge & Ward Law Port Allen, LA
CNJ1001	Parton & Universal Casualty Co. v. Diggs Construction, Inc. & George Guinn, et al.	Truck Accident Case / Bridge Failure; Expert Consultant, Report, Deposition	Chisenhall, Nestrud & Julian, PA Little Rock, AR
CNJ1101	Pryor Chemical Company v. Hoerbiger Services, Inc.	Compressor Failure & Oil Piping Review; Federal Court; Expert Consultant, Report	Chisenhall, Nestrud & Julian, PA Little Rock, AR
COLT0101	Henry J. Kaiser Company, Ltd. V. Colt Engineering & Comstock Canada, Ltd.		Colt Engineering Corporation Canada
CYKG1301	Hollybrook Cottonseed Processing, LLC v. Carter, Inc.		Cook, Yancey, King & Galloway Shreveport, LA
DBN1001	Police Jury of West Feliciana Parish v. Holly & Smith Architects, et al.	Piping / Water Damage to New Building	Degan, Blanchard & Nash Baton Rouge, LA
DDKF0601		Underground 10" Diameter Gas Line	Dukes, Dukes, Keating & Faneca, PA Gulfport, MS
DGPA1001	Kleen Energy	Plant Explosion; Middletown, CT	Douglas G. Peterson & Associat Inc.; Greenfield, MA
DIGL0801	Georgia Gulf	Furnace Inspection	The DiGiglia Law Firm, LLC Woodland Park, CO
DKS0901	Wilbros @ Marathon LOCAP (see related case: GRMR0901)	Oil Storage Facility Explosion w/ Fatality; TX State Court; Expert Consultant, Report	Deutsch, Kerringan, & Stiles, LLP New Orleans, LA
DKS1001	Team Industrial Services, Inc.	Trunkline Cases - Team Procedures; LA State Court; Expert Consultant, Report	Deutsch, Kerringan, & Stiles, LLP New Orleans, LA
DKS1002	Joel Willeby v. JE Merit & Exxon Mobil Corporation	Fire during valve repair; LA State Court; Expert Consultant, Testimony	Deutsch, Kerringan, & Stiles, LLP New Orleans, LA
DLA1001	Hollybrook Cottonseed Processing, LLC v. Lummus Corporation, et al.	Cotton Lint & oil processing; LA State Court; Expert Consultant, Report	DLA Piper Global Law Firm
DLA1101		Boiler Design, Operations, & Metallurgy	DLA Piper Global Law Firm
DMRS0401	New Jersey Pharmaceutical Plant	Construction / Fit-up / Engineering Problems; PA State Court; Consultant	Duane Morris, LLP Philadelphia, PA
DPHF1401	James Sistrunk v. Dake Corporation, et al.	Injury from Object Expelled from Press; Federal Court; Expert Report, Deposition	DeGravelles, Palmintier, Holthaus & Fruge, LLP; Baton Rouge, LA
DPHF1402	Kenneth Davidson v. Rockwell, et al.	Cabin Air Incident In-Flight; Federal Court; Consultant, Expert Report, Deposition	DeGravelles, Palmintier, Holthaus & Fruge, LLP; Baton Rouge, LA
DPHF1403	Joseph White v. Louisiana Fire Extinguisher, et al.	Injury from Exploded Air Cylinder; Federal Court; Consultant, Report, Deposition	DeGravelles, Palmintier, Holthaus & Fruge, LLP; Baton Rouge, LA
DUPR1201	Candice Kent	Water Meter Accident; Field Investigation	Due', Price, Guidry, Piedrahita & Andrews; Baton Rouge, LA
ELDR0501	DM Weatherly Nitric Acid Plant	Fire of October 8, 2004; AR State Court, Federal Court; Report, Depo, Testimony	El Dorado Chemical Company (EDCC) El Dorado, AR

FLB0501	Cherokee Nitrogen v. G.E. Preco, et al.	AL State Court; Consultant	Friedman Leak & Bloom, PC Birmingham, AL
FRBR0501	Allison / GM Model 250 Engine (see related case: KOSS0301)	FL State Court; Consultant, Trial Prep	Freidin Dobrinsky Brown & Rosenblum, PA; Miami, FL
GALW1301	Eugenia Morris v. CETCO Energy Services, et al.	Nitrogen Header Failure at CF Industries; LA State Court; Deposition	Gauthier & Amedee, APLC Gonzales, LA
GALW1401	Valerie Sept-Hasten v. Praxair Inc., et al.	Asphyxiation Due to CO Exposure; Federal Court; Expert Report, Deposition	Gauthier & Amedee, APLC Gonzales, LA
GJTB0101		Boat Chair Support Post Failure; FL State Court; Expert Report	Galloway, Johnson, Tompkins, Burr & Smith APLC; Mandeville, LA
GJTB0301	Thibodeaux, et al. v. Jervit B. Webb of Georgia	LA State Court; Expert Report, Deposition	Galloway, Johnson, Tompkins, Burr & Smith APLC; Mandeville, LA
GJTB0501	ATV Accident Investigation	LA State Court; Consultant	Galloway, Johnson, Tompkins, Burr & Smith APLC; Mandeville, LA
GLLL1301	Chad J. Gardemal v. Champion Technology Offshore Company, et al.	Injury from Tank Explosion	Gieger, Laborde, & Laperouse, LLC New Orleans, LA
GPPH0701	Failure Analysis of CL02 Piping		Georgia-Pacific Corporation Port Hudson, LA
GRDN1501	Jimmy Collins		Gordon McKernan Injury Attorneys Baton Rouge, LA
GRDN1502	Randolph Barnett v. City of Baton Rouge, et al.		Gordon McKernan Injury Attorneys Baton Rouge, LA
GREN0201		King Mountain Wind Farm Project	Greene & Associates, Inc. Addison, TX
GRMR0601	Degussa Engineering Carbons v. Edmeston	Failure Analysis of Tubesheet & Associated Piping; LA State Court; Consultant, Report	Germer Gertz, LLP Texas
GRMR0901	Wilbros @ Marathon LOCAP (see related case: DKS0901)	Oil Storage Facility Explosion w/ Fatality; TX State Court; Expert Consultant, Report	Germer Gertz, LLP Texas
HLHT1201		Pipe Inspection / Failure Case	Holland & Hart, LLP Denver, CO
HNTW0001	Studsvik, Inc. v. Metric Constructors / Duke Engineering & Services	Piping & Vessel Design Review & Analysis; Washington D.C.; Expert Report, Arbitration	Hunton & Williams, LLP Dallas, TX
HNTW0301	Polysius Corp. – Blue Circle / FaFarge	SC; Expert Consultant, Report, Arbitration	Hunton & Williams, LLP Dallas, TX
HNTW0401	Colgin v. Honeywell	Boiler Feed Water Flange Analysis; VA State Court; Expert Consultant	Hunton & Williams, LLP Dallas, TX
HNTW0601	Hanson Aggregates, Inc. v. Roberts & Schaffer	Plant Contruction / Performance Faults; Federal Court; Expert Consultant, Report	Hunton & Williams, LLP Dallas, TX
JBNT0201	Michael D. Davis v. Yamaha Motor Corporation	Skeeter Boat Review of Performance Characteristics Pursuant to Case	John T. Bennett Law Offices Marksville, LA
JBNT0301	Elaine Ogletree		John T. Bennett Law Offices Marksville, LA
KATS0002	Kaiser Technical Services	Kaiser Plant Explosion - Flash Tank & Blow-off Tank Analysis	Lemle Kelleher, LLP New Orleans, LA
KBKB1101	Gary Heath Warford v. Kimray, Inc.		Kitchens Benton Kitchens & Black Minden, LA
KCWL0701	Home Depot v. AAON	Roof mounted HVAC unit suspected as fire initiator	Keogh, Cox & Wilson, Ltd. Baton Rouge, LA
KCWL1101	Louis Robinson v. Tylan Meaus, et al.	City Sewer – Grease Pit Accident; Expert Consultant	Keogh, Cox & Wilson, Ltd. Baton Rouge, LA
KCWL1102	The Mosaic Company	Steam Boiler & Turbine; Expert Consultant	Keogh, Cox & Wilson, Ltd. Baton Rouge, LA

KCWL1201	Performance Contractors v. Great Plains Stainless	Review of Piping Components & Failure of Tee Connection; Expert Consultant	Keogh, Cox & Wilson, Ltd. Baton Rouge, LA
KCWL1202		Water Heater Failure	Keogh, Cox & Wilson, Ltd. Baton Rouge, LA
KOSS0301	Anofils v. General Motors, et al. (see related case: FRBR0501)	FL State Court; Consultant, Report, Depo	Law Offices of Russell Koss Tampa, FL
KRAT0301	Grimaldi v. Vivien & LSUNO	LSU Underground Hot Water Piping; LA State Court; Consultant, Report, Mediation	Kracht & Associates, LLC Baton Rouge, LA
KRLD0801	Dow Chemical Company	Dow Well No. 13 Casing Failure Analysis; LA State Court; Expert Consultant, Report	Kirkland & Ellis, LLP Chicago, IL
LMKL0501	ANR Pipeline v. Holloman Construction & National Union Fire Insurance	Petro. Condensate Explosion; LA State Court; Consultant, Report, Depo, Testimony	Lemle Kelleher, LLP Baton Rouge, LA
LONG0101	CFI v. Turner Industrial Services, Inc.	LA State Court; Deposition	Long Law Firm Baton Rouge, LA
LONG1101	Mosaic	Industrial Piping; LA State Court	Long Law Firm Baton Rouge, LA
MCDG0201	PCS Nitrogen, Trinidad	Review of Ammonia Converter; Canadian Court; Expert Consultant, Report	McDougall Gauley, LLP - Barrister & Solicitors; Canada
MCPP0701	Alabama Schools Plumbing Pipe Problems		Mann, Cowan & Potter, PC Birmingham, AL
METL0301	Claim #BL005311		MetLife Baton Rouge, LA
MILR0801	White Star Fire	Review of Causation Hydraulic Failure; LA State Court; Expert Consultant	Miller & Williamson, LLC New Orleans, LA
MTLN0001	Metalna	Crane Stability & Dock Study; Federal & International Court; Consultant, Report	Deutsch, Kerringan, & Stiles, LLP New Orleans, LA
NATW0201		1999 Ford Ranger Control Arm Failure	Nationwide Arbitrations & Inspection Tamarac, FL
PETR0101	File #18-3906 Nations Rental	I-R Compressor Flash; Expert Consultant, Report	Douglas G. Peterson & Associates, Inc.; Greenfield, MA
PETR0201		30" Pipe Failure Analysis	Douglas G. Peterson & Associates, Inc.; Greenfield, MA
PETR0401	Q. Lee Laundry	Steam Blowdown & System Review	Douglas G. Peterson & Associates, Inc.; Greenfield, MA
PHAK0101	Micro-Flex - Praxair - Sterling Chemical	Expert Consultant, Report, Mediation	Phillips & Akers, PC Houston, TX
RAIN1301	Douglas Youngblood v. RAIN CII Carbon, LLC	RAIN CII Personal Fall Arrest Trolley Incident; Expert Report	Sher Garner Cahill Richter Klein & Hilbert, LLC; New Orleans, LA
RBNK0301	Hartford Steam Boiler Inspection & Insurance Company	Incident at Flint Michigan: Gas Line Failure; MI State Court; Expert Consultant	Robins, Zelle, Larson & Kaplan San Francisco, CA
RDSM0301	PPG Plant @ LaPorte, TX	Piping Issues; Expert Consultant, Report, Arbitration Testimony	Reed Smith, LLP Pittsburgh, PA
RGLD1201		Deep Water Dock Feasibility Study	Ragland, Aderman & Associates, Inc. Baton Rouge, LA
RHOR1101	Taylor & Seymour v. Bogalusa	Municipal Water Chlorine Release	Rhorer Law Firm Baton Rouge, LA
RODL1301	David Wild v. Western World Insurance	Open Hole in Base Flooring	Roedel, Parson, Koch, Blache, Balhoff & McCollister; Baton Rouge, LA
ROHN0701	Belgrave, Teddy, et al. v. Hovensa, LLC	Planned for Arbitration	Law Offices of Rohn & Cameron, LLC; St. Croix, Virgin Island

ROHN0702	Apolinar Acevedo v. Amerada Hess Corporation		Law Offices of Rohn & Cameron, LLC; St. Croix, Virgin Island
RUSK0201		Ammonia Plant Re-Start Study	John Ruskin, Attorney New Orleans, LA
SAUN1301	Terry Ferrington v. McMorna Oil & Gas, LLC	Oil Platform Waste Disposal Container; Federal Court	Saunders & Chaubert Baton Rouge, LA
SCO1501	O'Neal v. Mitsubishi Electric	In-Plant Rail System Stress Analysis; Arbitration	Smith Cashion & Orr Nashville, TN
SFC0801	Causey @ McComb, MS	Water Loss	Safeco Insurance Metairie, LA
SHAW1101	Amegy Bank National Assoc. v. Brazos M&E, Ltd.	Shaw Pipe Removal Project; Bankruptcy Court, Houston; Expert Consultant, Report	The Shaw Group, Inc. Baton Rouge, LA
SHFR0701	Tchoupitoulas St. v. London Co., Catlin Ins., Ltd., Alea London, Ltd., & Forest Ins.	Building Storm Damage; Expert Consultant, Report	Schafer & Schafer New Orleans, LA
SHWN0001	Hatch v. Kaiser Aluminum	Boston; Expert Consultant, Report, Mediation Testimony	Shaw-Norton
SMSH1201	Tripp v. Welton USA, Rent-A-Center East, Inc., Store #2716	Injury from Bunk Bed	Smith Shanklin Sosa, LLC Baton Rouge, LA
SOLA1101	Hunt Correctional Center	Underground Pipe Leaks Pre-Insulated Cool / Hot Water	State of LA Division of Administration Baton Rouge, LA
STNP1101	AmericasStyrenics, LLC v. Excel Contractors, Inc. & Excel Maintenance, Inc.	6" Natural Gas Piping Damage; St. James, LA; Legal Consultation	Stone Pigman Walther Wittmann, LLC; Baton Rouge, LA
STPL1201	Elizabeth Roundtree v. Publix Supermarket, Inc.	Leaking Oil Bottle in Publix Store / Injury	Desmond H. Staple, PA Tampa, FL
TADV0501	Hall v. McWayne		Technical & Medical Advisors San Francisco, CA
TCM0201	Stacy Sibley v. Exxon Corporation	East Coker Fire on August 2, 1993; Federal Court; Expert Consultant, Report, Depo	Talbot, Carmouche & Marcello Baton Rouge, LA
TETN0701	Teton Industrial Construction, Inc. v. Siemens Power Generation, Inc.	Power Plant Const., Pipe Review, & Stress Analysis; FL; Expert Consultant, Mediation	Sutherland Asbill & Brennan, LLP Altanta, GA
TLSM1101	Baraki Tsegaye v. City of New Orleans, et al.	Failed Lamp Post	Thomas L. Smith – Attorney at Law Zelienople, PA
TRUT0101		Oil Pipeline Failure Investigation	Trutanich Michel, LLP Long Beach, CA
WEYR0703		Crane Failure	Weyerhaeuser Company Philadelphia, MS
WFC1301	Dana & Herbert Wilson v. National Display, et al.	Display Rack / Personal Injury	Williamson, Fontenot & Campbell, LLC; Baton Rouge, LA
WKCC0901	Kansas City Southern Railway	KCSR Railroad Tank Car Hand Rail Separation; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1101	Andray Terrell Gilbert v. Kansas City Southern Railway	Railroad Car Door / Injury; Expert Consultant, Report	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1102		Motor Jack Hydraulic Hose Failure; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1103	Lester Metcalf v. Kansas City Southern Railway	Injury from Railroad Switch; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1104	Brad Abrams v. Kansas City Southern Railway	Injury from Locomotive Hand Brake; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1105	Terry K. Mathews v. Kansas City Railway	Injury from Rollover Switch; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1106		Zeno – Highway Depris; Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA

WKCC1201	David Lee Fontenot v. Kansas City Southern Railway	PPG Industries Tank Car Gasket Leak	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1301	Kansas Cirt Southern Railway v. Precision Land Leveling, LLC, DSK, Ltd., & ABC Ins.	KCSR Train Derailment; Forensic Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1302	Klayton Shoales v. Kansas City Southern Railway	Field Investigation	Wilkinson, Carmody & Gilliam Shreveport, LA
WKCC1303		Sand Crane Failure	Wilkinson, Carmody & Gilliam Shreveport, LA
WPTC1501	Renewable Energy Group, Inc.	REG Plant Fire - September 4, 2015; Geismar, LA	Walter, Papillion, Thomas, Cullens, LLC; Baton Rouge, LA

Reg No:	SerialNo:	Date:	AFTT:	AFTC:	Page	WO#
N690EH	11309	6/24/2011	11943	9295.0	1 of 1	275

Maintenance Notes

Troubleshoot strong odor in the cabin air system especially noticeable during high altitude flight with heat on high and max flow selected. Inspected all the duct work from the engines and found no trace of oil or residue. Found no engine oil leaks that would contribute to any oil smell in the cabin. Tested the compressor seal per instructions from CD Aerospace-both engines compressor pressures were normal so no evidence of possible bypass of fumes into the cabin. Inspected the ACM oil level and found that it was at the same level as if had been 50 flight hours prior to this work. Removed the duct work from the mixing plenum to the ACM, ACM to cabin air plenum, cabin air plenum to the lower fwd cabin air distribution-no abnormalities were noted. Replaced both plenum air ducts IT-201-24-128-6, both ducts under the baggage floor to the cabin 880158-513 (due to leaks noted during pressurization checks) and duct NW2W2S12-128-4 located on the ACM. Investigated why the cabin cooling system was not functioning-discovered that the hot air valve was remaining in full open position when temp controller system was in auto mode. Valve was controllable in manual mode. Replaced the temp controller HYLZ50340 with an overhauled controller s/n 644. Also found the upper and lower air inlet duct sensors were out of calibration-readjusted both sensors to the limits specified in the Commander AMM. Removed the heat exchanger cleaned and pressured tested for leaks-no leaks noted. Reinstalled in the original configuration. Removed the ACM. Tested function and rotor drag test on the bench. Found the unit needed 1 1/2 inch pounds of torque to rotate. Engineer contacted at Fairchild (ACM Manufacturer) stated that any reading under 10 inch pounds was sufficient. Further inspected the unit and found no discrepancies-reinstalled in the aircraft. Pressurization system was pressure checked for leaks-none noted. Ground run of the temp control systems revealed that the cool air system was now functioning-the hot air valve was modulating normally. Ground and flight checks revealed that the system was working normally and no further odors were detected. Work Performed By: Kevin Stephen 1a

Ran diagnostic check on the fuel quantity system per instructions included with the S.T.C. installation instructions. All resistance values were in line with troubleshooting instructions. Emptied the aircraft of fuel. Adjusted the fuel quantity system IAW Commander LLC ICA instructions document 469-23.1329. All checks were good. Work Performed By: Michael P. Jones

Completed torque indication system check IAW tpe-331-5 lmm Page 72-00-00 Para 3.B on the left and right engines. Indicators are correct for torque. Performed ITT thermocouple harness test on both engines IAW TPE-331-5 LMM pg 77-20-03 para 3. Perfromed ITT compensating resistance adjustment check IAW TPE-331-5 LM pg 77-20-03 para 2D and found that the resistors were within limitsof the DSC sheet left engine setting #11 right setting #23. No defects were noted on the ITT system. Work Performed By: Kevin Stephen

Found the right main gear down/lock indicator light green cover and reattached the cover to the bulb. Ground check was good. Work Performed By: Billy S. Guest

Excessive avionics interference and noise repoerted by the pilot and ATC. Found the mic jacks PTT not grounded at a central ground per the Signtronics SDB-800 installation manual. Corrected the wiring-systems ground and flight ops checks good. Wiring diagram updated to include the intercom wiring. Work Performed By: Michael P. Jones

certify this Aircraft has been repaired and was found to be airworthy for the work performed and is pproved for return to service IAW FAR 43.9

John T Probst | [signature] | A&P 192248

Printed Name	Signature	Certificate No.

NORTHROP GRUMMAN

Airframe Logbook Entry

Reg No:	SerialNo:	Date:	AFTT:	AFTC:	Page:	WO#
N690EH	11309	8/1/2011	11975	9295.0	1 of 1	279

Maintenance Notes

Ground ran the aircraft to verify the oily odor and reported smoke in the aircraft. Verified that there is, under certain conditions when max heat is selected, smoke that can be seen and a strong oily odor is apparent. This is a continuing problem since first reported and initially corrected in June 2011. Removed the ACM to inspect for any possible cause. When the end of the turbine duct was removed there were signs that the turbine had contacted the outer wall and also the tips of the turbine blades were slightly damaged. Installed an overhauled ACM, part number 977018-1, S/N 0335 using a gasket kit supplied with the unit. Installed new duct hose assemblies 880158-513. Ground test was good. It was also discovered during the maintenance check that the cabin inlet duct temp was greatly affected when the auto temp control box was removed from the cabin wall. New insulation was added to the wall area directly behind the control box to insulate the box from the outside skin temperature. Ground checks confirmed that the system was working normally. Work Performed By: John F. Probst

I certify this Aircraft has been repaired and was found to be airworthy for the work performed and is approved for return to service IAW FAR 43.9

John F. Probst	[signature]	A&P 1922489
Printed Name	Signature	Certificate No.

Engines bearing the same part number, though similar in characteristics, are not identical. This, coupled with tolerable error in the torque, rpm, fuel flow, and temperature indicators, often causes differences in instrument readings between normal, healthy engines. Engine performance should be monitored for daily changes and trends as compared with original installed torque, fuel flow and ITT values. Cockpit readings obtained on each flight will aid greatly in monitoring engine performance.

The trouble shooting procedures are based on the symptoms which the engine displays to the operator, as well as procedures of the Aircraft Flight Manual for starting and operating the engine. There is no deliberate duplication of troubles presented - that is, a trouble which would become apparent when the engine is being started would not be covered in later operating modes. Simple and easily diagnosed troubles such as loose connections or incorrect control settings are not covered.

Table 101 provides specific maximum allowable fuel or oil leakages from engine components as an aid to determining component serviceability.

NOTE: As the majority of engine installations indicate fuel flow in pounds per hour, this unit of measurement is used in the following procedures.

Table 101. Fluid Leakage Limits

Location and Type	Maximum Allowable Limits
Fuel Pump Assembly Drive Pad	
Fuel	5.0 cc/hr
Oil	0.5 cc/hr (approx eight drops per hr)
Hydraulic Pump Drive Pad	0.5 cc/hr (approx eight drops per hr)
Accessory, Tachometer-Generator, or Starter-Generator Shaft Seal (oil)	0.5 cc/hr (approx eight drops per hr)
Fuel Pressure Regulator Drain Connection (fuel)	
During Regulator Operation	10.0 cc/min
During Normal Engine Running	1.0 cc/min
Fuel Control Assembly Drain (fuel)	1.0 cc/min
Flow Divider and Drain Valve Drain (fuel)	5.0 cc/min
Propeller Shaft Seal	0.5 cc/hr (approx eight drops per hr)
Compressor Seal (oil) (as viewed at air inlet) (Static leak only)	1.0 cc/min (approx 15 drops per min)

39905

TPE FLUID LEAKAGE LIMITS FOR REPAIR ENGINES

LOCATION AND TYPE	MAXIMUM ALLOWABLE LIMITS
FUEL PUMP ASSEMBLY DRIVE PAD	
FUEL	5.0 CC/HR.
OIL	0.5 CC/HR. (APPROX. EIGHT DROPS PER HR.)
HYDRAULIC PUMP DRIVE PAD	0.5 CC/HR. (APPROX. EIGHT DROPS PER HR.)
ACCESSORY, TACHOMETER-GENERATOR, OR STARTER-GENERATOR SHAFT SEAL (OIL)	0.5 CC/HR. (APPROX. EIGHT DROPS PER HR.)
FUEL PRESSURE REGULATOR DRAIN CONNECTION (FUEL) (TPF331-5-6)	
DURING REGULATOR OPERATION	10.0 CC/MIN.
DURING NORMAL ENGINE RUNNING	1.0 CC/MIN.
FUEL CONTROL ASSEMBLY DRAIN (FUEL)	1.0 CC/MIN.
FLOW DIVIDER VALVE DRAIN (FUEL)	5.0 CC/MIN.
PROPELLER SHAFT SEAL	0.5 CC/HR. (APPROX. EIGHT DROPS PER HR.)
TURBINE SEAL (OIL): CHECK LEAKAGE DURING OPERATION BY MONITORING OIL CONSUMPTION OF ENGINE. CONSUMPTION SHALL NOT EXCEED ONE QUART PER TWELVE AND ONE HALF HOURS OPERATION. ENGINE SHALL NOT EMIT SMOKE TO INDICATE EXCESSIVE LEAKAGE DURING OPERATION.	(STATIC LEAKAGE NOT PERMITTED)

Table 101. Fluid Leakage Limits (Cont)

Location and Type	Maximum Allowable Limits
Turbine Seal (oil) (Check leakage during operation by monitoring oil consumption of engine. Consumption shall not exceed one quart per twelve and one half hours operation. Engine shall not emit smoke to indicate excessive leakage during operation.)	1.0 cc/min (approx 15 drops per min)

1b

in the front, what happens to the air after that, how you get combustion and so forth.
A. Yes, when the air comes in the front of the engine, it goes through the compressors and various of stages in the compressor. This aircraft has two stages of compressor air.
The turbine blades are in the back of the engine, and they are in the hot gas path. So, as air is started, when you start the aircraft, you use a regular -- a starter to spin this engine until you get up to a certain -- it's called N1, a certain speed on the compressor section, where there is enough air for the ignition to happen. So when that happens, fuel is introduced into the air path that's -- and it's ignited, which causes the turbine blades to start to spin, which causes the propellers to start to spin. And it's all, just basically a perpetual motion machine after that. Once ignition has happened, these engines will run without any ignition system. Now, the only control you have over a turbine engine, is how much fuel you put in it.
Q. Does this --
A. This --
Q. I'm sorry. Were you finished, sir?
A. I think so, yes.

Q. The 57-2 shows, it's kind of color coordinated here. Does it depict the air first going into the airway.
A. Uh-huh. Yeah, that's right.
Q. Does that depict the air going to the stages of the compressor section?
A. Right. Uh-huh.
Q. And when it gets to those two stages of the compressor section, is it accurate to say that the compressor blade compresses the air to a much higher pressure than it was when it came in, they also make it hotter because of the fact it was compressed?
A. That's right. Yes, as the air enters the compressor side, each section, it increases in pressure, and it also increases in temperature. And that's the whole point of it.
Q. Now, we talked in this case about bleed air. What is bleed air?
A. Well, it's air that's tapped off of the compressor section, and it's used for this airplane, this engine operation and airframe, up to 20 percent of the compressed air is available for pressurization and air conditioning and all kinds of other operations in the aircraft.

Q. And you said up to 20 percent is used as bleed air. Would it we accurate then that 80 percent or more of the air then, is it not bled off after it's sent back towards the combustion section for using combustion and the creation of power?
A. Yeah, that's right.
Q. The bleed air then is used for pressurization comes off the first part of the engine ahead of the combustion area; is that correct?
A. That's right.
Q. Now, once that bleed air comes off those engines -- let me back up a little bit. On the Commander, does the pressurization system operate normally with bleed air from both engines?
A. It does. That's right.
Q. Is there a plumbing system of some sort to get that bleed air to the cabin of the aircraft?
A. Yes, there are bleed air lines that run from that tap off of the engine, and then run through the wing into the back of the aircraft, into a --
Q. And where does it go? When it gets in the back of aircraft, does it go into an air cycle machine?
A. Well, it ends up at the air cycle machine, some of it does. But it ends -- it goes into a clone

system, which then, based on what temperatures you're asking for in the cabin, it modulates -- some of it goes overboard, and some of it gets pressurized in the cabin. There's many varieties and ways it's used. But it comes into a plenum to begin with.
Q. Okay.
A. And that is diverted depending on what's being called for by the command -- by the pilot.
Q. And what does the air cycle machine do?
A. It increases the volume of air by speeding up this -- it gives you more volume, so you have more volume to be able to blow up that cabin with the pressure that you need.
Q. Okay. I've been talking in this case about the fact that -- about the use of turbine engine oil in particular. Does this aircraft use BP turbo oil 2380?
A. It does.
Q. Is that oil used in both the left engine and the right engine?
A. It is.
Q. Is it also used in the air cycle machine?
A. That's correct. It is.
Q. How much of that oil is actually used in the reservoir or consistent reservoir of the air

2a

2b

cycle machine?
A. It's a tiny amount. It's less than a pint. It's contained in a wick system that it takes days for it to drain out. It's stays in a wick system. All it's doing is -- it's boiling two bearings that are in that system, in that compressor, that little air cycle machine.
Q. We've taken a deposition of a Dr. Robert Harrison who is a physician in California, and he has suggested that Mr. Davidson might have been exposed or was exposed to leaking turbine engine oil in his Commander.
My question to you is this: Are there any possible forces of bleed air contamination by turbine engine oil other than from the two engines and from the air cycle machine on this particular aircraft?
A. There's no other possibility. Those are the only places there's oil.
Q. Now again, we're here because Mr. Davidson says he was exposed to the fumes from the cabin, an oil leak in the cabin, both in the cabin, on May 31st of 2011.
When did you first hear about that incident, sir?
A. The exact date is -- I'm not sure of the

exact date. We -- it wasn't -- I just don't remember exactly. I'm sorry. But it was earlier.
Q. Was it days after it happened?
A. Yes, it was almost immediately. We -- the crew is in contract with that office all the time, almost daily with any kind of issues. But I don't exactly remember the exact date. No, I don't.
Q. We've been told by Mr. Tom Farmer and also Mr. Davidson, that they flew the aircraft back to Peachtree City, Georgia, I believe, on June 1st, 2011 unpressurized.
Does that ring a bell with you at all?
A. Oh, yes, yes. As soon as we knew there was an issue with the aircraft, we immediately stopped operating the aircraft and asked them to bring it home unpressurized and low altitude so they didn't have to pressurize the airplane.
Q. Now, we've got -- you faxed us some aircraft -- airplane logbook entries, two pages. Do you have those with you, sir?
A. I do.
Q. And tell us very briefly, what -- when an aircraft has maintenance done, is it required for regulation that that maintenance be recorded in an appropriate logbook?

A. It is. It has to return to service to allow the aircraft to fly again, it has to be properly documented and put in the permanent records, and signed off by an appropriate person.
MR TRAHAN: I'm going to ask the court reporter, please, if you could, to have Mr. Probst identify those two pages I just mentioned, and identify those or label them as Exhibit 2, please.
(Exhibit No. 2 was marked for identification.)
THE WITNESS: Okay. That's done.
Q. (By Mr. Trahan) Okay. Mr. Probst, could you look at the first page, please? I see an entry there, I believe, for June 24, 2011; is that correct?
A. That's right. Uh-huh.
Q. Is that entry reflective of the first maintenance or repair work on that aircraft following the incident of May 31st of 2011?
A. Yes.
Q. I'm going to have you go ahead and read to us what took place, just read your maintenance note, and I'll stop you periodically to have you explain which aircraft you're talking about in these notes. Would you start from "please" and tell us what you

recorded there.
A. Okay. I -- we -- it says, Troubleshoot strong odor in the cabin air system, especially noticeable during high altitude flight with heat on high and maximum flow selected. Inspected all the duct work from the engines, found no trace of oil or residue.
Q. Let me stop you right there if I could. Tell us exactly what was done then as far as inspection of duct work and how did you-all look for any traces of oil leaks.
A. Yes, we removed both ends of the duct, so that we had access to it. And we routed Borescope at first through the duct work and found nothing.
Q. What's a Borescope, please?
A. It's a -- it's a device that you can -- you can inspect in a -- in normally areas where you couldn't see. It's got a long tube on it, and it has a fiber optics camera in it. And you can run it down through a duct work or anything, and inspect the area. It's got a magnifier on it.
Q. And could you do anything else? We talked about the duct work inspection --
A. Yes.
Q. Did you do anything else to try to detect

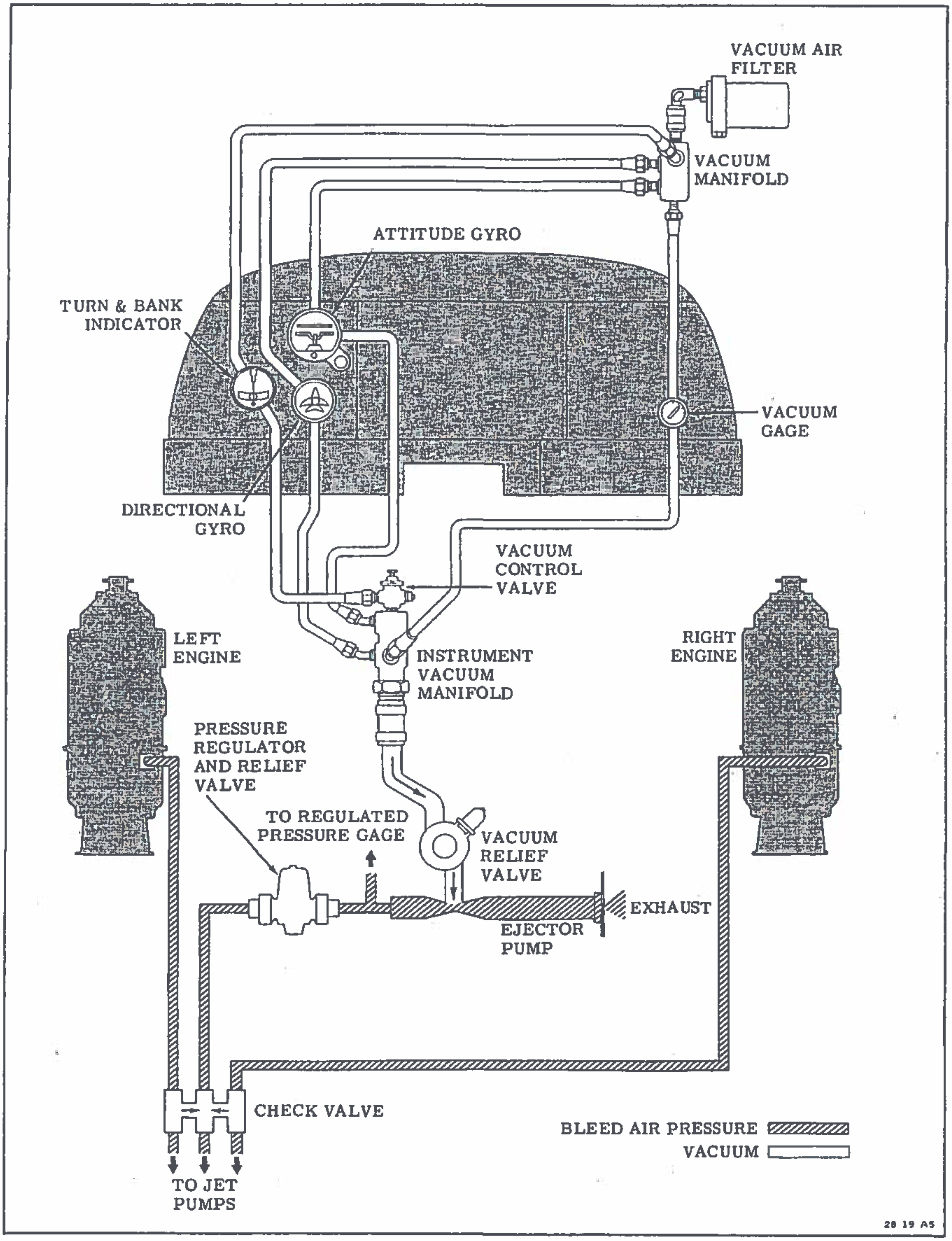


Figure 8-2. Vacuum System Schematic

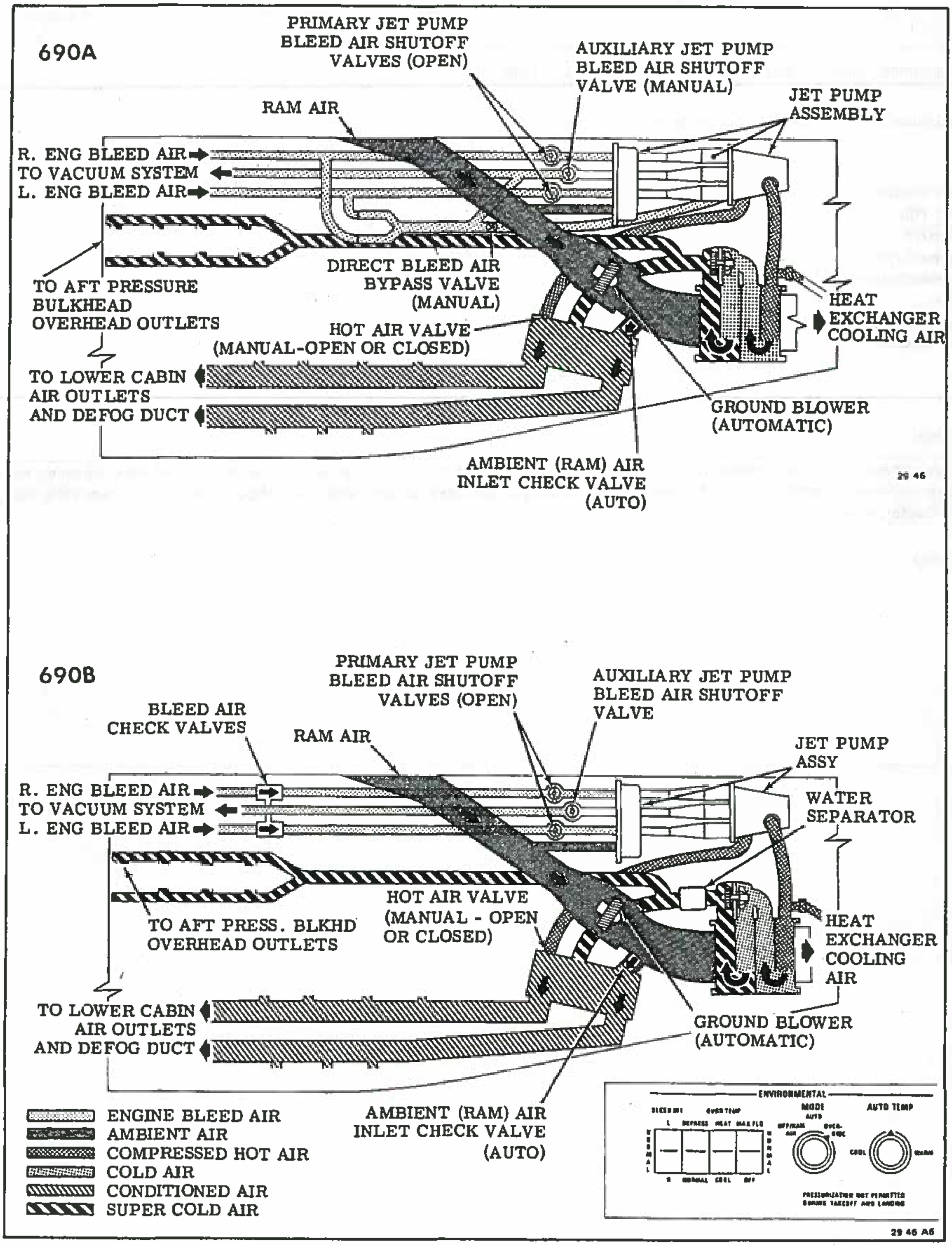


Figure 9-8. Override Condition

- **Part Number:** 1910
- **Part Title:** Occupational Safety and Health Standards
- **Subpart:** J
- **Subpart Title:** General Environmental Controls
- **Standard Number:** 1910.146
- **Title:** Permit-required confined spaces
- **Appendix:** A, B, C, D, E, F
- **GPO Source:** e-CFR

1910.146(a)

Scope and application. This section contains requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. This section does not apply to agriculture, to construction, or to shipyard employment (Parts 1928, 1926, and 1915 of this chapter, respectively).

1910.146(b)

Definitions.

"Acceptable entry conditions" means the conditions that must exist in a permit space to allow entry and to ensure that employees involved with a permit-required confined space entry can safely enter into and work within the space.

"Attendant" means an individual stationed outside one or more permit spaces who monitors the authorized entrants and who performs all attendant's duties assigned in the employer's permit space program.

"Authorized entrant" means an employee who is authorized by the employer to enter a permit space.

"Blanking or blinding" means the absolute closure of a pipe, line, or duct by the fastening of a solid plate (such as a spectacle blind or a skillet blind) that completely covers the bore and that is capable of withstanding the maximum pressure of the pipe, line, or duct with no leakage beyond the plate.

"Confined space" means a space that:

(1) Is large enough and so configured that an employee can bodily enter and perform assigned work; and

(2) Has limited or restricted means for entry or exit (for example, tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry.); and

(3) Is not designed for continuous employee occupancy.

"Double block and bleed" means the closure of a line, duct, or pipe by closing and locking or tagging two in-line valves and by opening and locking or tagging a drain or vent valve in the line between the two closed valves.

"Emergency" means any occurrence (including any failure of hazard control or monitoring equipment) or event internal or external to the permit space that could endanger entrants.

"Engulfment" means the surrounding and effective capture of a person by a liquid or finely divided (flowable) solid substance that can be aspirated to cause death by filling or plugging the respiratory system or that can exert enough force on the body to cause death by strangulation, constriction, or crushing.

"Entry" means the action by which a person passes through an opening into a permit-required confined space. Entry includes ensuing work activities in that space and is considered to have occurred as soon as any part of the entrant's body breaks the plane of an opening into the space.

"Entry permit (permit)" means the written or printed document that is provided by the employer to allow and control entry into a permit space and that ontains the information specified in paragraph (f) of this section.

"Entry supervisor" means the person (such as the employer, foreman, or crew chief) responsible for determining if acceptable entry conditions are present at a permit space where entry is planned, for authorizing entry and overseeing entry operations, and for terminating entry as required by this section.

NOTE: An entry supervisor also may serve as an attendant or as an authorized entrant, as long as that person is trained and equipped as required by this section for each role he or she fills. Also, the duties of entry supervisor may be passed from one individual to another during the course of an entry operation.

"Hazardous atmosphere" means an atmosphere that may expose employees to the risk of death, incapacitation, impairment of ability to self-rescue (that is, escape unaided from a permit space), injury, or acute illness from one or more of the following causes:

(1) Flammable gas, vapor, or mist in excess of 10 percent of its lower flammable limit (LFL);

(2) Airborne combustible dust at a concentration that meets or exceeds its LFL;

NOTE: This concentration may be approximated as a condition in which the dust obscures vision at a distance of 5 feet (1.52 m) or less.

(3) Atmospheric oxygen concentration below 19.5 percent or above 23.5 percent;

(4) Atmospheric concentration of any substance for which a dose or a permissible exposure limit is published in Subpart G, Occupational Health and Environmental Control, or in Subpart Z, Toxic and Hazardous Substances, of this Part and which could result in employee exposure in excess of its dose or permissible exposure limit;

NOTE: An atmospheric concentration of any substance that is not capable of causing death, incapacitation, impairment of ability to self-rescue, injury, or acute illness due to its health effects is not covered by this provision.

(5) Any other atmospheric condition that is immediately dangerous to life or health.

OTE: For air contaminants for which OSHA has not determined a dose or permissible exposure limit, other sources of information, such as Material Safety Data Sheets that comply with the Hazard Communication Standard, section 1910.1200 of this Part, published information, and internal documents can provide guidance in establishing acceptable atmospheric conditions.

"Hot work permit" means the employer's written authorization to perform operations (for example, riveting, welding, cutting, burning, and heating) capable of providing a source of ignition.

"Immediately dangerous to life or health (IDLH)" means any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects or that would interfere with an individual's ability to escape unaided from a permit space.

NOTE: Some materials -- hydrogen fluoride gas and cadmium vapor, for example -- may produce immediate transient effects that, even if severe, may pass without medical attention, but are followed by sudden, possibly fatal collapse 12-72 hours after exposure. The victim "feels normal" from recovery from transient effects until collapse. Such materials in hazardous quantities are considered to be "immediately" dangerous to life or health.

"Inerting" means the displacement of the atmosphere in a permit space by a noncombustible gas (such as nitrogen) to such an extent that the resulting atmosphere is noncombustible.

NOTE: This procedure produces an IDLH oxygen-deficient atmosphere.

"Isolation" means the process by which a permit space is removed from service and completely protected against the release of energy and material into the space by such means as: blanking or blinding; misaligning or removing sections of lines, pipes, or ducts; a double block and bleed system; lockout or tagout of all sources of energy; or blocking or disconnecting all mechanical linkages.

"Line breaking" means the intentional opening of a pipe, line, or duct that is or has been carrying flammable, corrosive, or toxic material, an inert gas, or any fluid at a volume, pressure, or temperature capable of causing injury.

"Non-permit confined space" means a confined space that does not contain or, with respect to atmospheric hazards, have the potential to contain any hazard capable of causing death or serious physical harm.

"Oxygen deficient atmosphere" means an atmosphere containing less than 19.5 percent oxygen by volume.

"Oxygen enriched atmosphere" means an atmosphere containing more than 23.5 percent oxygen by volume.

"Permit-required confined space (permit space)" means a confined space that has one or more of the following characteristics:

(1) Contains or has a potential to contain a hazardous atmosphere;

(2) Contains a material that has the potential for engulfing an entrant;

(3) Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or

(4) Contains any other recognized serious safety or health hazard.

"Permit-required confined space program (permit space program)" means the employer's overall program for controlling, and, where appropriate, for protecting employees from, permit space hazards and for regulating employee entry into permit spaces.

"Permit system" means the employer's written procedure for preparing and issuing permits for entry and for returning the permit space to service following termination of entry.

"Prohibited condition" means any condition in a permit space that is not allowed by the permit during the period when entry is authorized.

"Rescue service" means the personnel designated to rescue employees from permit spaces.

"Retrieval system" means the equipment (including a retrieval line, chest or full-body harness, wristlets, if appropriate, and a lifting device or anchor) used for non-entry rescue of persons from permit spaces.

"Testing" means the process by which the hazards that may confront entrants of a permit space are identified and evaluated. Testing includes specifying the tests that are to be performed in the permit space.

NOTE: Testing enables employers both to devise and implement adequate control measures for the protection of authorized entrants and to determine if acceptable entry conditions are present immediately prior to, and during, entry.

1910.146(c)

General requirements.

1910.146(c)(1)

The employer shall evaluate the workplace to determine if any spaces are permit-required confined spaces.

NOTE: Proper application of the decision flow chart in Appendix A to section 1910.146 would facilitate compliance with this requirement.

1910.146(c)(2)

Regulations (Standards - 29 CFR) - Table of Contents

- **Part Number:** 1910
- **Part Title:** Occupational Safety and Health Standards
- **Subpart:** Z
- **Subpart Title:** Toxic and Hazardous Substances
- **Standard Number:** 1910.1000 TABLE Z-1
- **Title:** TABLE Z-1 Limits for Air Contaminants.
- **GPO Source:** e-CFR

TABLE Z-1 LIMITS FOR AIR CONTAMINANTS

NOTE: Because of the length of the table, explanatory Footnotes applicable to all substances are given below as well as at the end of the table. Footnotes specific only to a limited number of substances are also shown within the table.

Footnote(1) The PELs are 8-hour TWAs unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples.

Footnote(a) Parts of vapor or gas per million parts of contaminated air by volume at 25 degrees C and 760 torr.

Footnote(b) Milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate.

Footnote(c) The CAS number is for information only. Enforcement is based on the substance name. For an entry covering more than one metal compound measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

Footnote(d) The final benzene standard in 1910.1028 applies to all occupational exposures to benzene except in some circumstances the distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures; for the excepted subsegments, the benzene limits in Table Z-2 apply. See 1910.1028 for specific circumstances.

Footnote(e) This 8-hour TWA applies to respirable dust as measured by a vertical elutriator cotton dust sampler or equivalent instrument. The time-weighted average applies to the cotton waste processing operations of waste recycling (sorting, blending, cleaning and willowing) and garnetting. See also 1910.1043 for cotton dust limits applicable to other sectors.

Footnote(f) All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by the Particulates Not Otherwise Regulated (PNOR) limit which is the same as the inert or nuisance dust limit of Table Z-3.

Footnote(2) See Table Z-2.

Footnote(3) See Table Z-3

Footnote(4) Varies with compound.

Footnote(5) See Table Z-2 for the exposure limits for any operations or sectors where the exposure limits in 1910.1026 are stayed or are otherwise not in effect.

TABLE Z-1. - LIMITS FOR AIR CONTAMINANTS

Substance	CAS No. (c)	ppm (a) (1)	mg/m(3) (b) (1)	Skin designation

compounds (except oxides) (as Sn)......	7440-31-5	....	2	
Tin, organic compounds (as Sn).............	7440-31-5	....	0.1	
Titanium dioxide.......	13463-67-7			
Total dust...........		....	15	
Toluene................	108-88-3		(2)	
Toluene-2, 4-diisocyanate (TDI).	584-84-9	(C)0.02	(C)0.14	
o-Toluidine...........	95-53-4	5	22	X
Toxaphene; see Chlorinated camphene.				
Tremolite; see Silicates........				
Tributyl phosphate.....	126-73-8	....	5	
1,1,1-Trichloroethane; see Methyl chloroform				
1,1,2-Trichloroethane..	79-00-5	10	45	X
Trichloroethylene......	79-01-6		(2)	
Trichloromethane; see Chloroform				
Trichloronaphthalene...	1321-65-9	....	5	X
1,2,3-Trichloropropane.	96-18-4	50	300	
1,1,2-Trichloro-1,2, 2-trifluoroethane....	76-13-1	1000	7600	
Triethylamine..........	121-44-8	25	100	
Trifluorobromomethane..	75-63-8	1000	6100	
2,4,6-Trinitrophenol; see Picric acid......				
2,4,6-Trinitrophenyl-methyl nitramine; see Tetryl...........				
2,4,6-Trinitrotoluene (TNT)................	118-96-7	....	1.5	X
Triorthocresyl phosphate............	78-30-8	....	0.1	
Triphenyl phosphate....	115-86-6	....	3	
Turpentine.............	8006-64-2	100	560	
Uranium (as U).........	7440-61-1			
Soluble compounds....		....	0.05	
Insoluble compounds..		....	0.25	
Vanadium...............	1314-62-1			
Respirable dust (as V_2O_5))...........		....	(C)0.5	
Fume (as V_2O_5).......		....	(C)0.1	
Vegetable oil mist.....				
Total dust...........		....	15	
Respirable fraction..		....	5	
Vinyl benzene; see Styrene..........				
Vinyl chloride; see 1910.1017........	75-01-4			
Vinyl cyanide; see Acrylonitrile				
Vinyl toluene..........	25013-15-4	100	480	
Warfarin...............	81-81-2	....	0.1	
Xylenes (o-, m-, p-isomers)..	1330-20-7	100	435	
Xylidine...............	1300-73-8	5	25	X
Yttrium................	7440-65-5	....	1	
Zinc chloride fume.....	7646-85-7	....	1	
Zinc oxide fume........	1314-13-2	....	5	

Zinc oxide	1314-13-2			
Total dust		....	15	
Respirable fraction		....	5	
Zinc stearate	557-05-1			
Total dust		....	15	
Respirable fraction		....	5	
rconium compounds (as Zr)	7440-67-7	....	5	

Footnote(1) The PELs are 8-hour TWAs unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples.

Footnote(a) Parts of vapor or gas per million parts of contaminated air by volume at 25 degrees C and 760 torr.

Footnote(b) Milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate.

Footnote(c) The CAS number is for information only. Enforcement is based on the substance name. For an entry covering more than one metal compound measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

Footnote(d) The final benzene standard in 1910.1028 applies to all occupational exposures to benzene except in some circumstances the distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures; for the excepted subsegments, the benzene limits in Table Z-2 apply. See 1910.1028 for specific circumstances.

Footnote(e) This 8-hour TWA applies to respirable dust as measured by a vertical elutriator cotton dust sampler or equivalent instrument. The time-weighted average applies to the cotton waste processing operations of waste recycling (sorting, blending, cleaning and willowing) and garnetting. See also 1910.1043 for cotton dust limits applicable to other sectors.

Footnote(f) All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by the Particulates Not Otherwise Regulated (PNOR) limit which is the same as the inert or nuisance dust limit of Table Z-3.

Footnote(2) See Table Z-2.

.note(3) See Table Z-3

Footnote(4) Varies with compound.

Footnote(5) See Table Z-2 for the exposure limits for any operations or sectors where the exposure limits in 1910.1026 are stayed or are otherwise not in effect.

[54 FR 36767, Sept. 5, 1989; 54 FR 41244, Oct. 6, 1989; 55 FR 3724, Feb. 5, 1990; 55 FR 12819, Apr 6, 1990; 55 FR 19259, May 9, 1990; 55 FR 46950, Nov. 8, 1990; 57 FR 29204, July 1, 1992; 57 FR 42388, Sept. 14, 1992; 58 FR 35340, June 30, 1993; 61 FR 56746, Nov. 4, 1996; 62 FR 42018, August 4, 1997; 71 FR 10373, Feb. 28, 2006]

Next Standard (1910.1000 TABLE Z-2)

Regulations (Standards - 29 CFR) - Table of Contents

Jet engine oil consumption as a surrogate for measuring chemical contamination in aircraft cabin air

Jeremy J. Ramsden*

The University of Buckingham, MK18 1EG, UK

A considerable number of measurements of aircraft cabin air contamination with more or less toxic substances has been carried out to date, but there are significant differences between the reported results. This may reflect a possible reality of differences between different aircraft types at different stages in their engine maintenance cycles; unfortunately most of the reports do not give sufficient detail in this regard. On the other hand the measurements are intrinsically difficult and the lack of agreement may reflect systematic errors due to inappropriate methodologies. In the absence of any comprehensive comparative review, no definite conclusion regarding the discrepancies can be drawn. In this paper, an independent estimate of the contamination is made based on the assumption that it originates from the bleed air and using engine oil consumption as the primary parameter. An estimate is also made of the aerial concentration of contaminants in a typical fume event, which has not yet been reliably measured directly.

1. INTRODUCTION

Ever since the system of pressurizing jet aircraft cabins using hot compressed air bled off the engines ("bleed air") was introduced, aeronautical engineers have been aware of the possibility, indeed inevitability, of some contamination of the bleed air and, hence, of the ambient atmosphere in the cockpit and cabin, with engine oil [28]. The composition of jet oil is typically about 96% synthetic ester (e.g., esters of pentaerythritol and pentanoic acid), 3% tricresyl phosphate (added as an antiwear agent, as an iron-passivating agent to inhibit the iron-catalysed decomposition of the ester, and as a fire retardant) and 1% N-phenyl-α-naphthylamine (usually abbreviated as PAN, also known as N-phenyl-1-naphthylamine, added as an antioxidant) [18, 19]. In operation, the oil may be heated to several hundred °C, at which some decomposition is likely to take place, the products of which appear to be toxic [33]. Furthermore, at least some of the isomers of tricresyl phosphate (TCP) are known to be potent neurotoxins [11], notably those containing at least one *ortho* substituent.

Although the health and *a fortiori* (in severe cases) safety risks from inhaling engine oil contaminating the bleed air cannot be considered to be negligible, as with other spheres of human activity, such as motoring, the benefits have been assumed to outweigh the disbenefits.[1] Traditionally, attention to chemical contamination of aircraft cabin air has focused on small-molecule gases such as carbon dioxide, carbon monoxide and ozone [32]. Nevertheless, the recognition that bleed air contamination can occur focuses attention on the oil constituents, among which, as mentioned, tricresyl phosphate is a potent neurotoxin. The neurological (including behavioural) sequelae of TCP ingestion by humans have been documented for many tens of thousands of cases and innumerable animal experiments have been subsequently carried out [1]; inhalation is, of course, a much more effective way of dosing a subject than ingestion [25]. Documented cases of pilot ill health following a "fume event" [20], which we can define as the significant and sudden ingress of oil-based contamination into the cabin, to a degree that it is actually visible as smoke, and probably due to the catastrophic failure of one of the oil seals separating the oil from the air in the engine, has engendered the suspicion that those frequently exposed to cabin air, especially pilots, cabin attendants and perhaps frequently flying passengers as well, might suffer occupational neurological disease with an insidious onset due to the long-term, chronic exposure. This suspicion has led to attempts to measure oil contamination in the cabin, which is technically significantly more demanding than measurement of the small molecules.

The effort required to realize such measurements is considerable. For example, investigations of the Swedish Board of Accident Investigation (SHK) following a suspected fume event included collection and analysis of the cabin air, requiring the removal of 29 passenger seats from the aircraft [31]. In order to minimize the space

* E-mail: jeremy.ramsden@buckingham.ac.uk.

[1] For example, Chaturvedi writes, "Despite health issues associated with air travel, there are enormous benefits of this mode of travel to travelers, to commerce, to international affairs, and to health" [5].

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required for the instrumentation, the most popular procedure is to collect the contamination by pumping the air through sample tubes packed with adsorbent, which is subsequently (post-flight) desorbed and analysed in a laboratory on the ground [30]. Based on the premiss that the rather involatile oil components are likely to condense on the internal surfaces of the aircraft (including the ducting leading the bleed air into the cabin), these surfaces have also been analysed [4, 30, 14], which gives at least a qualitative indication of past contamination.

Such measurements as have been carried out have been rather inconclusive.[2] Reviewing previous work, Nagda and Rector commented in 2003 that "such a limited dataset does not permit definitive conclusions" [23]. Subsequently, van Netten found up to about 100 ng/m^3 of TCP using the sample tube approach, although only two measurements were made and details of the calculation of the contamination concentration were not given [24].[3] Solbu et al., using a similar approach, failed to detect any TCP at all [30]. Denola et al., also using sample tubes, were actually able to identify four of the individual isomers of TCP, the total concentration of which was measured as 51.3 μg/m^3 in an actual fume event [8]. Unfortunately they did not give details of their actual analytical procedure, hence it is not possible to properly evaluate this result.[4] The most comprehensive (10 flight phases for each of a hundred flights) study to date was that made by Crump et al., using a combination of sample tubes and on-board particle and photoionization detectors [7]. Although this study has been subjected to some criticism [6, 22] it nevertheless provides the best data currently available. The concentration of TCP averaged over all measurements was 0.22 μg/m^3 [7].[5] An unexpected feature of the results of Crump et al. [7] is that the ratio of tri-*ortho*-cresylphosphate (T*o*CP) to total TCP was much higher than what can be deduced from the composition of the modern commercial TCP that is presumably what is blended into the base oil [27] (during the past few decades intensive efforts to eliminate T*o*CP, because of its known potent neurotoxicity, from the commercial product at reasonable cost have been made). The reason for this discrepancy is still unknown.[6]

It is noteworthy that none of the analytical procedures described in any of the studies hitherto reported have been validated by collecting samples in an environmental chamber containing calibrated aerial concentrations of TCP and the other contaminants that have been measured. This absence provides the primary motivation for independently estimating the likely concentration of engine oil contamination in cabin air. It is well known that a typical jet engine uses "about one quart an hour" of oil, in SI units this is 0.26 cm^3/s. The purpose of this paper is to estimate the resulting concentration of oil in the cabin air assuming that all of it is lost via the bleed.

2. FIRST CALCULATION

From data provided by Hocking the typical ingress of external air in an aircraft like the A320 (in which the maximum number of seats is 179 [13]) can be deduced to be about 1 m^3/s [12]. This aircraft has two engines, therefore the maximum oil ingress is 0.52 cm^3/s, of which about 3% = 0.016 cm^3/s is TCP. The density of TCP may be taken as 1.17 g/cm^3 [10, 29], hence the ingress is about 18 mg/s. This immediately gives us a maximum aerial concentration c_{max} = 18 mg/m^3 for total TCP.

6e

The 8-hour workplace exposure limit (WEL) for T*o*CP is 0.1 mg/m^3 [9]; if this were indeed applicable to an aircraft cabin in high-altitude flight as implied by Crump et al. [7], although of course it is not, the actual concentration might be almost two hundred times in excess of that limit. The fact that it has been measured to be about 80,000 times less than 18 mg/m^3 [7], with the reservation that the measurements may have significantly underestimated the quantity,[5] presumably reflects the fact that the bulk of the oil continuously lost by the engine is vented into the outside atmosphere. The fraction of about 10^{-5} of the lost oil actually leaking into the cabin is a measure of the quality of the oil seals separating the oil and (bleed) air circuits [18].

In the event of a catastrophic oil seal failure, which is presumed to be the cause of fume events in which the entire cabin is filled with smoke (e.g., Figure 1 in ref. [26]), the concentration of oil is likely to increase by many

[2] See Appendix 10 of ref. [17] for a comprehensive list and summaries of published and unpublished studies between 1979 and 2006.

[3] Most investigations have focused on measuring TCP because of its well established neurotoxicity, despite the fact that partially combusted or pyrolysed base oil has been shown to be toxic [33] and may be present at a comparable concentration.

[4] The readers of the Denola et al. paper are referred to report no DSTO-RR-0292 (2005) for full details of the experimental methods, but the authors of that report, which include the authors of the paper, are unwilling to allow it to be released, on the grounds of commercial confidentiality.

[5] Crump et al.'s value is the arithmetic mean of all the individual determinations, assigning readings below the detection limit to a value of zero; hence this average must be an underestimate.

[6] One possibility, not discussed in ref. [27], is that there is an additional source of T*o*CP apart from the engine oil—TCP is used as a plasticizer in certain (vinyl) polymers [29], and this provides a possible, albeit improbable, source for the excess T*o*CP.

orders of magnitude; the mass concentration of smoke leading to a comparable visibility loss could be $c_{f.c.}$ = 50 mg/m^3 [21]. This implies that the rate of loss of the oil will increase more than twofold.

Swabs taken from the internal surfaces of aircraft have revealed the presence of contamination characteristic of engine oil constituents [30, 14]. Such results are, however, only indicative of the contamination because they cannot be quantitatively related to any particular level of aerial contamination. Adsorption on surfaces will obviously tend to diminish the aerial concentration. Supposing that all these surfaces are very far from being saturated with contamination, the actual rate of adsorption R_{ads} is simply

$$R_{ads} = sFA \qquad (1)$$

where s is the "sticking factor" (the probability that an incoming particle will stick to the surface), F is the particle flux and A is the total adsorbent area. Since these calculations are approximate we shall take s = 1 (the area A of course comprises different kinds of surfaces, such as metal (oxide), polymer, textile and skin, each of which would have a different s). The appropriate expression for the flux will depend on the phase of the oil, which is discussed in §3.

3. THE PHASE OF THE AERIAL OIL

The synthetic base oil and the additives are rather involatile substances and it may be presumed that oil leaking from the engine into the aircraft cabin exists as an aerosol (oil mist). If 0.2 μm is taken as the typical diameter of droplets, they have a volume of 4.2×10^{-21} m^3; hence 1.2×10^{14} oil droplets, dispersed in 1 m^3, would enter the cabin each second if all the lost oil actually leaked into the cabin.

The boiling points of the various isomers of TCP range from 200 to 400 °C [11, 10, 29, 3]. The vapour pressure P_{TCP} is 10–100 μPa at room temperature; aircraft cabins are usually pressurized to about P = 75 kPa (corresponding to an altitude of 8000 feet above sea level), hence the expected aerial equilibrium concentration in the presence of liquid TCP, P_{TCP}/P, would be only 1.3×10^{-9} ppm, which corresponds to a mass concentration of (P_{TCP}/P) M_r/V_{NTP}, where the molecular weight M_r of TCP is 368 and V_{NTP} is the volume of 1 mole of gas at normal temperature and pressure (24.45 dm^3), about 20 pg/m^3. Therefore, we may safely deduce that TCP will not be inhaled as a vapour but as an aerosol, in all probability dissolved in the base oil.

Ultrafine particle counts as measured by Crump et al. typically fell in the range 10^9–10^{11} m^{-3} [7]. The lower end of this range would agree with the fraction of lost oil actually leaking into the cabin deduced from the TCP measurements (§2). The precise number, of course, depends on the size of the droplets, which is only estimated in this calculation.

4. ADSORPTION ONTO INTERNAL SURFACES

The Brownian flux of aerosol particles to the internal surfaces could be estimated using

$$F = Dc/\delta \qquad (2)$$

where D is the diffusivity of the particle, which can be calculated using the Stokes–Einstein relation,[7] = 11×10^{-11} m^2/s (keeping the particle radius r = 100 nm as before), c is the particle concentration and δ is the thickness of the aerodynamic (Blasius) boundary layer. The aerodynamics of the airflow in the interior of an aeroplane cabin is of course an exceedingly complicated matter and, not surprisingly, resort has been had to computational fluid dynamics for studying it (e.g., refs [2, 16]). We shall take an average value of δ = 10 mm. This yields F = 10^7 m^{-2}s^{-1} for c = 10^{14} m^{-3}.

Taking the A320-200 as a typical aircraft example, the fuselage is (approximately[8]) 40 m long and has a radius of 2 m [13, 12], giving a volume of 500 m^3 (of which half is occupied by the passenger cabin and the cockpit). The inner surface of the fuselage has an area of approximately 500 m^2. The actual surface is much greater because the cabin is filled with seats and passengers. Let us approximate this additional surface by the area of the 179 passengers who could be accommodated; the average area of the human body is approximately 2 m^2, giving a total of about 360 m^2, and a grand total of 860 m^2.

From eqn (1) we therefore calculate the rate of loss of particles as 8.6×10^9 s^{-1}. This is many orders of magnitude less than the maximum oil ingress (under normal operation); if c is taken as 10^{10} m^{-3}, (roughly the middle of the range found by Crump et al. [7]) we shall have a rate of loss of particles of ~10^5 s^{-1}, from which we can conclude that adsorption onto the internal surfaces within the aircraft cabin does not significantly diminish the aerial concentration.

Lamb et al. found TCP deposits of about 30 μg/m^2 [14].[9] Using F = 10^3 m^{-2} s^{-1} for c = 10^{10} m^{-3}, and keeping other variables the same (3% TCP), the rate of deposition of TCP is about 1.5×10^{-13} g m^{-2} s^{-1}, implying that exposure

[7] $D = k_BT/(6\pi\eta r)$, where η is the viscosity of the air, taken to be 20 μPa s [15].
[8] Numbers here and elsewhere are appropriately rounded.
[9] Depending on aircraft type and location. This result is typical for the B757.

for 2×10^8 s would be needed to accumulate the amounts found, assuming that the TCP is irreversibly deposited and does not decompose on the surfaces. This estimate seems to be perfectly reasonable; it corresponds to 555 flying days of 10 h flying per day. Unfortunately no details of the aircraft, other than type, are given in Lamb et al.'s study [14].

5. CONCLUSIONS

Comparison of the known rate of loss of engine oil during jet engine operation with measurements of ultrafine particle concentration (assumed to consist of oil droplets) and tricresyl phosphate (the most significant minor component of the oil) suggests that a fraction 10^{-5}–10^{-4} of the oil leaks into the aircraft cabin, where it can be inhaled by aircrew and passengers.

This is during normal operations. The oil concentration in an actual fume event, in which visible smoke appears in the cabin, is estimated at 50 mg/m^3. The corresponding concentration of TCP is about 1.5 mg/m^3. If the ratio of ToCP to total TCP found in ref. [7] is representative [27], this corresponds to a ToCP concentration of 0.5 mg/m^3—well exceeding the short-term workplace exposure limit (15 minute reference period) [9], which is, as already pointed out, applicable to a terrestrial factory environment.

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ORIGINAL RESEARCH

Cognitive function following exposure to contaminated air on commercial aircraft: A case series of 27 pilots seen for clinical purposes

SARAH MACKENZIE ROSS

Sub-department of Clinical Health Psychology, University College London, Gower Street, London WC1E 6BT, UK

Abstract

Background. Cabin air on commercial aircraft is sometimes contaminated with hydraulic fluids, synthetic jet engine oils and combusted or pyrolized materials. The incidence of contaminated air events is hard to quantify as commercial aircraft do not have air quality monitoring systems on board. In the UK, around 350 aircrew have advised their union that they may be suffering physical and psychological ill health following exposure to contaminated air.

Design. This paper presents a case series of 27 pilots referred for psychological assessment. The general aim of the assessment was to determine whether pilots show evidence of cognitive impairment and whether this relates to exposure history.

Materials and method. All pilots underwent neuropsychological and adult mental health assessment, undertaken by 12 examiners, instructed to search for alternative explanations other than exposure to toxic fumes for any symptoms reported.

Results. Pilots reported alarming cognitive failures at work such as being unable to retain or confusing numerical information from Air Traffic Control. Nine pilots were excluded from further analysis because they had a medical or psychiatric condition which might otherwise explain these difficulties. In the remaining 18 pilots, language, perceptual skills and general intellectual ability were preserved, but performance on tests of psychomotor speed, attention and executive functioning was below expected levels.

Conclusions. The cognitive deficits identified in this cohort of pilots cannot be attributed to factors such as mood disorder or malingering. However, the evidence available in this study does not enable firm conclusions to be drawn regarding a causal link with contaminated air; the cohort of pilots was self-selected and only crude indices of exposure were available. Further research is warranted given the scientific uncertainty regarding the health effects of inhalation of heated or pyrolized engine oil.

Key words: *Aviation air quality, cognitive impairment, memory, occupational exposure, organophosphates, pilots*

Introduction

To enable passengers and crews to live in a reduced pressure environment, aircraft cabins are pressurized and the air supply to the passenger cabin and cockpit is supplied from the

Correspondence: Sarah Mackenzie Ross, Sub-department of Clinical Health Psychology, University College London, Gower Street, London WC1E 6BT, UK. Tel: + 44 (0) 20 7679 1258. Fax: + 44 (0)20 7916 1989. Email: s.mackenzie-ross@ucl.ac.uk

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engines or auxiliary power unit. This air is unfiltered and known as 'bleed air' and is sometimes contaminated with hydraulic fluids, synthetic jet engine oils and/or the compounds released when these fluids and/or oils are heated or pyrolized (for example, carbon monoxide, phosphorus oxides, aldehydes). When the 'bleed air' becomes contaminated in this way it is referred to as a 'contaminated air' event. Contaminated air may contain a large number of chemicals which can cause irritation, skin sensitization and neurotoxicity such as the organophosphate tricresyl phosphate (TCP) [1–3]. It is recognized that all aircraft are subject to engine oil leaks occasionally but certain types of aircraft record statistically more events than others. These include the BAe 146, A320 and Boeing 757 [4].

The incidence of contaminated air events on commercial aircraft is difficult to quantify as commercial aircraft do not have air quality monitoring systems on board. Under-reporting of contaminated air events is common amongst aircrew due to lack of awareness, commercial pressure and fears over job security if crew complain about working conditions and many crews see contaminated air as a normal, everyday occurrence. A recent survey by the British Airline Pilots Association (BALPA) found that only 61 out of 1667 contaminated air events (that is, only 3.66%) were recorded on the UK Civil Aviation Authority (CAA) database [5].

No monitoring has ever been successfully undertaken during a contaminated air event [6]. Therefore, the nature of the contaminants within the cabin air and the levels of exposure to passengers and crews during a contaminated air event are unknown. The material data safety sheets for jet engine oils BP 2380 (widely used in BAe 146 aircraft) and Exxon Mobil Jet Oil II (widely used in Boeing 757 aircraft) states that TCP is present in the oil and warn that toxic and harmful fumes/vapours/mists may be evolved on burning or exposure to heat and that exposure to thermal decomposition products in an enclosed space may cause headache, nausea, eye, nose and throat irritation. One study found the organophosphate tricresylphosphate (TCP) on the walls of BAe 146 aircraft, a BAe 146 pilots' trousers, Boeing 757 dust and HEPA filters [7].

Flight attendants, flight crew and some passengers around the world have been reporting ill health following contaminated air events for many years [3,5,8], but it is only recently that this issue has received attention in the UK. The immediate effects of exposure to contaminated air have been well documented and include eye irritation, respiratory problems, headache, skin problems, nausea, vertigo, loss of balance, dizziness, fatigue and cognitive impairment (disorientation, confusion and memory problems). These symptoms show a close temporal relationship with exposure and usually recede after cessation of exposure [1,5,9].

A number of individuals report persistent, chronic ill health lasting months or years after exposure, including lack of coordination, nausea/vomiting, diarrhoea, respiratory problems, chest pains, severe headaches, lightheadedness, dizziness, weakness and fatigue, parasthesias, tremors, increased heart rate, palpitations, irritation of ear, nose and throat, muscle weakness/pain, joint pain, salivation, skin itching, rashes, blisters, hair loss, signs of immunosuppression and chemical sensitivity [3,10–12]. Persistent cognitive impairment has also been reported involving memory problems, reduced information processing speed, reaction time and fine motor skills [13]. Work incapacity may be as high as 35% [10]. A debate is ongoing in the UK and US about causation, diagnosis and treatment of long-term effects.

This paper presents a case series of 27 commercial airline pilots who requested or were referred by other specialists for neuropsychological assessment. The pilots had concerns about their health and a number suggested their symptoms might be related to exposure to

contaminated air on commercial aircraft. All pilots underwent neuropsychological and adult mental health assessment and their medical records were reviewed to determine whether they had a previous medical or psychiatric history which might otherwise account for their symptoms.

Method

Basis for project

Around 350 UK pilots have advised their union that they may be suffering health effects from exposure to contaminated air. The pilots union maintains a database of these individuals. This paper presents a case series of 27 aircrew who underwent psychological assessment for clinical purposes. The general aims of this case study were:

(1) To establish whether aircrew with a history of exposure to contaminated air on commercial aircraft show evidence of cognitive impairment.
(2) To examine the nature and extent of any cognitive deficits identified.
(3) To determine whether the pattern of cognitive deficit relates to exposure history.

Subjects

The subjects for this project were a self-selected sample of 27 commercial airline pilots who voluntarily underwent neuropsychological assessment and adult mental health assessment. All bar one of the aircrew involved in this audit were current or former pilots on the Boeing 757 or BAe 146 aircraft types.

Seven pilots were referred by either a general medical practitioner or a medical specialist (consultant neurologist or consultant psychiatrist) for an opinion regarding their cognitive functioning. The remaining 20 aircrew referred themselves directly (self-referral) and were retired, suspended and working pilots who fly/flew the BAe146 and Boeing 757 aircraft, who had reported exposure to contaminated air to union officials.

Ethics approval

All pilots were asked if their results from psychometric testing could be entered into a group analysis and all pilots gave written consent for this. Ethical approval for this work was granted by the joint UCL/UCLH committee on the Ethics of Human Research, Committee A.

Clinical interview

A clinical interview collected information, as outlined in Table I. Whenever possible, a relative/carer was interviewed as well to obtain corroborating evidence.

In addition, a complete set of each individual's general medical notes and any relevant hospital records were reviewed by the author to search for alternative explanations for any symptoms or deficits identified during the assessment.

Neuropsychological assessment

Subjects underwent a detailed neuropsychological assessment which lasted ~3 hours. After a short break they undertook a clinical interview and mental health assessment which lasted

Table I. Information collected during clinical interview.

Developmental and social history
Educational and occupational background
Past medical and psychiatric history; alcohol, drug and medication use
Recent stressful life events (for example, bereavement, divorce)
Exposure history. Pilots were asked to bring details of their career history including
• detailed records of flying hours (from their log books)
• the year they began flying
• which aircraft they had flown over the course of their career
• how long they had spent flying each aircraft type
• whether they thought they had ever experienced exposure to contaminated air, if so, did they suffer from any physical or psychological symptoms
• how long did the symptoms persist and did they recover
• did they report the incident(s) to any authorities
• were incident(s) investigated by engineers?
• did they have any long-term/persistent health problems which they attribute to exposure to contaminated air?
• had they consulted any doctors about their symptoms?
• what diagnoses have been given?
Onset of physical/psychological problems and their temporal relationship with exposure, plus their evolution over time
The nature of any medical treatment provided
Current symptoms/problems (physical, emotional, cognitive)
Impact on daily life
Mood state

~2 hours. Twelve examiners were involved in assessing aircrew; all examiners were blind to exposure status.

Psychometric assessment

Psychometric testing was carried out first to ensure the examiners were blind to the precise exposure status of the aircrew they were testing. Examiners were only given basic demographic information such as the name and age of the study participant they were seeing and they were aware that the pilots had been referred because they believed their health to have been affected by exposure to contaminated air. All examiners were instructed to search for explanations other than exposure to toxic fumes, for any symptoms or deficits identified during assessment. In particular they were asked to consider the possibility that symptoms might be secondary to excessive alcohol consumption or substance abuse, previous neurological injury, medical or psychiatric history, lifestyle factors, malingering, mood disorder, psychosomatic disorder, stressful life events or attribution error. In addition, examiners were instructed to ask subjects if they had been examined by a Consultant Neurologist to exclude other potential explanations for their symptoms and to report what diagnoses they had been given by any other medical experts they might have seen.

Only well known, reliable and clinically sensitive measures were selected for inclusion in the Psychometric test battery [14]. Tests were selected which would assess a broad range of cognitive functions including premorbid and current IQ, language skills, memory functioning (verbal and visual), information-processing speed, executive function and visuo-perceptual ability. A test of malingering was also included in the battery. Finally, emotional state at the time of testing was assessed using the Hospital Anxiety and Depression Scale (see Table II).

Table II. Psychometric battery.

Premorbid and current IQ
Wechsler Adult Reading Test (WTAR) [21]
Wechsler Adult Intelligence Scale–III (WAIS-III) [22]
Memory
Adult Memory and Information Processing Battery (AMIPB) [23]
Information Processing Battery and Psychomotor speed
Adult Memory and Information Processing Battery
Trail Making A
Language
Graded Naming [24]
Verbal Fluency (FAS) [25]
Semantic fluency (Animals)
Malingering test
Rey 15 item
Mental flexibility
STROOP [26]
Trail Making B
Perception
Benton Line Orientation [27]
Benton Face Recognition (short form)
Mood questionnaires
Hospital Anxiety and Depression Scale [28]
Beck Depression Inventory-II
Beck Anxiety Inventory
Life Events Checklist [29]

Descriptive information is provided for all 27 pilots regarding exposure history, physical symptoms associated with exposure and the results of various medical tests aimed at establishing the aetiology of these complaints.

Nine individuals were found to have a medical or psychiatric history which might otherwise account for any cognitive deficits identified during assessment and these were excluded from the group analysis of cognitive function. The rationale for this exclusion process was to ensure the most conservative analyses of the data in order to reduce the risk of false positive results. Reasons for exclusion were: alcohol intake above 21 units/week (2 pilots); anxiety and/or depression (2 pilots); co-morbid neurodegenerative condition (2 pilots); neurological symptoms of unknown aetiology (1 pilot); and 'others' (2 pilots).

Results

Demographic and exposure information

Demographic information is shown in Table III.

Flying hours. Table IV shows the total number of hours and years that pilots had spent flying throughout their career history and the total number of hours they had flown specific aircraft types. None of the pilots who flew/fly the Boeing 757 had flown the BAe146 and contrariwise, but all pilots had flown other aircraft types during their career history. The sample was equally split with regard to aircraft type flown with nine pilots having flown the Boeing 757 and nine having flown the BAe 146.

Table III. Demographic characteristics of aircrew.

Characteristics	Pilots	
	whole sample (n=27)	reduced sample (n=18)
Gender	3 Female; 24 Male	2 Female; 16 Male
Mean age years (±SD: range)	49.4 (±8.2: 36–63)	48.4 (±8.8: 36–62)
Mean educational level (±SD: range)	13.2 (±2.3: 10–18)	13.2 (±2.3: 10–18)
Mean WAIS-III full scale IQ (±SD: range)	119.9 (±13.9: 88–155)	119.3 (±10.5: 103–139)
Working aircrew	13	9
Long-term sick leave or medical suspended?	5	4
Retired on ill health grounds	6	2
Retired for other reasons	3	3

Table IV. Flying time and hours on specific aircraft types (reduced sample).

	Lifetime flying (hours)	Lifetime flying (years)	Boeing 757 hours	BAe 146 hours
Mean	11 642	22	1978	2647
SD	5 349	10.7	2742	3052
Range	3 000–25 000	5.5–40	0–8000	0–8147

A flying hour is not the same as time in the aircraft environment as it does not include time in the cockpit prior to engine start or after engine shut down completing pre- and post-flight duties.

Official reporting of fume incidents. All of the pilots examined reported unpleasant, oily, chemical smells in the aircraft cabin which would increase in intensity under certain conditions.

Pilots who fly/flew the BAe 146 describe the cabin as having a distinctive and unpleasant oily, chemical smell, the intensity of which would increase under the following conditions: (1) when the air conditioning system is turned on; (2) during 'pack burns', an operational procedure in which the aircraft air-conditioning system is operated at full heat so as to volatize hydrocarbons from the air conditioning system into the aircraft cabin whilst it is empty (although crew were sometimes present setting up the aircraft for its next flight [15,16]. Pack burns were reported to be performed regularly to remove oil contamination of the ductings and often caused visible fumes in the aircraft cabin which crews were exposed to (3) during take off, climb, descent and landing.

Pilots who fly/flew the Boeing 757 describe the cabin as having a distinctive and unpleasant oily, chemical smell, the intensity of which would vary depending on phase of flight and power settings on the engines.

Ten pilots stated that they had never formally reported contaminated air for the following reasons: (1) they assumed the distinctive smell in the cabin was part of the normal working environment and not something to be unduly concerned about; (2) fears over job security if contaminated air events were reported. Two pilots were threatened by senior colleagues when they suggested reporting an event; (3) a belief that the company would not act on the report; (4) not wishing to be delayed at work completing the necessary paperwork; and (5) not attributing symptoms of ill health to contaminated air. The remaining 17 pilots had reported a contaminated air event at some point during their career history.

Symptoms provoked by exposure and the development of chronic ill health

Acute symptoms. Thirteen pilots describe one or more of the following acute symptoms which develop immediately after exposure to contaminated air; flu-like symptoms, watering eyes, sore nose, throat, nasal congestion, breathing difficulties, headache, nausea, gastrointestinal problems, dizziness, fatigue, cognitive impairment (that is inability to complete basic tasks such as mental arithmetic or to follow instructions in the correct sequence). A number of pilots describe a metallic taste in the mouth following exposure. These symptoms usually resolve on cessation of exposure.

The cognitive impairment reported by pilots was alarming, bearing in mind the nature of the symptom and the consequences of an adverse outcome: being unable to retain numerical coordinates provided by Air Traffic Control regarding height, altitude, speed; mixing up the numerical coordinates provided by Air Traffic Control; completing tasks in the incorrect sequence; being able to hear Air Traffic Control or colleagues talking to them, but being unable to respond; feeling intoxicated; feeling unable to make decisions or problem-solve; losing track of conversations; word-finding difficulties; being easily distracted and unable to return to the task in hand; being unable to recall important matters such as whether the undercarriage had been raised or lowered. Several pilots reported being unaware of the extent of their impairment until it was pointed out to them by colleagues. Others found it necessary to request assistance from colleagues to complete their duties.

Long-term symptoms. All bar one pilot reported the development of more persistent, chronic health problems over time including fatigue, sleep difficulties, fluctuating gastro-intestinal problems, numbness and tingling in fingers and toes, memory and word-finding difficulties.

Two of the BAe 146 pilots reported feeling so fatigued at work that they had micro-sleeps whilst flying aircraft, that is they fell asleep whilst in control of the aircraft. All of the pilots who complained of fatigue described it as being intense and overwhelming and quite unlike fatigue which is precipitated by exercise or sleep deprivation. They also report that this chronic fatigue persists even after sleep/rest. Nine continued to work, one pilot was on long-term sick leave, two have retired on ill health grounds and three have retired for personal choice.

In most cases long-term symptoms develop gradually or after a major fume event, but three 757 pilots describe a marked deterioration in health following a viral illness which left them with disabling levels of fatigue and an inability to work. One of these pilots has fully recovered (though he has not returned to work for other reasons) but the others have not and have ceased flying. None of these three pilots formally reported fume events, though they did consult their GP about recurrent flu-like symptoms in the years preceding the sudden development of chronic ill health.

Neuropsychological functioning

Pilots underwent an extensive battery of more than 30 neuropsychological tests. There was no evidence of global intellectual decline or impairment, language or perceptual deficits in this cohort. Indeed, pilots were intact on the vast majority of tests. However, there was evidence of under-functioning on tests associated with psychomotor speed, executive functioning and attention.

Intellectual functioning. The average level of intelligence was on the border of the high average/superior range for the general population (mean full scale IQ was 119, SD ± 10.5).

Scores ranged from being average to very superior (IQ score range 103–139). None were below average.

With regard to WAIS-III sub-tests, 61% of the cohort obtained scores on a test of visual sequencing and psychomotor speed (digit symbol) which were statistically significantly different from their mean performance on other sub-tests within the WAIS-III. This means the likelihood of obtaining such a difference by chance is very low. Fifty per cent of the cohort obtained scores on a test of working memory/attention (digit span) which were statistically significantly different from their mean performance on other sub-tests within the WAIS-III; and 33% of the cohort obtained scores on another test of visual sequencing (picture arrangement) which were statistically significantly different from their mean performance on other sub-tests within the WAIS-III. Table V illustrates these findings, along with those of the only other neuropsychological study in this area [13]. The prevalence or frequency of most of the observed differences (that is two thirds) are rare in the standardization sample (that is less than 10% of the standardization sample would show differences of this magnitude).

To summarize, deviations in sub-test scores of this magnitude are unexpected. Not only are there a large number of participants who show deviations in sub-test scores, the deviations are apparent on the same sub-tests.

Executive functioning—mental flexibility. Fifty per cent and 39% of pilots obtained scores below the 50th percentile on tests of attention/mental flexibility (Stroop and Trails B) and 44% obtained low scores on a test of semantic fluency. These tests are all associated with executive functioning.

Information processing speed. Fifty per cent of pilots obtained scores below the 50th percentile on tests of mental information processing speed and 33% had a higher than

Table V. Psychometric test results.

Tests	Percentage impairments	
	Present study	Coxon study [13]
Visual Sequencing		
Digit Symbol	61%	87.5%
Picture Arrangement	33%	62.5%
Memory (verbal)		
Digit Span (working memory)	55%	50%
Story Recall	78%	87% impaired on verbal recall
List Learning	55%	
Memory (visual)		
Figure Recall	5%	50% impaired on visual recall
Design Learning	16%	
Executive (Frontal Lob) Function		
Stroop	50%	*
Trails B	39%	37.5%
Semantic Fluency	44%	
Information Processing Speed		
Mental Speed	50%	*
Motor Speed	17%	*
Increased Error Rate	33%	*

* comparable data not available.

average error rate on this test. In contrast, motor speed is relatively well preserved with only three pilots obtaining weak scores on this test.

Memory. All but two pilots were of high average to very superior intelligence, yet 78% obtained scores in the average or low average range on some aspect of a story recall test, 33% obtaining scores 1–2 SD below the mean. Fifty per cent obtained scores in the average range on a list learning task, 28% obtained scores 1–2 SD below the mean on this test.

In contrast, visual memory seemed to be relatively well preserved with only two pilots showing a weakness in this area.

Malingering test. None of the pilots included in the group analyses failed the malingering test.

Mood questionnaires. Any pilot with elevated scores on the Hospital Anxiety and Depression Scale or Beck Inventories underwent a structured interview to determine whether they met DSM-IV criteria for Major Depression or Anxiety Disorder. None of the pilots included in the group analysis met DSM-IV criteria for a diagnosis of anxiety or depression.

Statistical analyses

Comparison with a control group. As was mentioned at the beginning of this report this is not a research study, but an audit of a case series of aircrew examined during the course of clinical practice. Funding was not available to recruit a suitable, matched control group. However, the author has data on 22 healthy, non-exposed individuals, recruited from local job centres within London and newspaper advertisements, who completed the same psychometric test battery as the pilots, although matched to the sample of pilots in terms of gender, age and years spent in education, level of intelligence differed between the groups. The mean Wechsler Adult Intelligence Scale Full Scale IQ in the control group was at the top of the average range, whilst the average full scale IQ in the pilot cohort was at the top of the high average range (see Table VI).

As the two groups are not well matched in terms of IQ, statistical tests of differences in mean are less informative than tests of profile. In other words, while the pilot group had a higher overall mean, impairments in psychological performance might be indicated by a different pattern of performance across sub-tests. This was tested using profile analysis. Bonferroni corrections were applied to control for Type 1 errors. The analysis confirmed an overall difference in mean between the two groups ($F(1,39)=10.48$, $p=0.002$), but more importantly showed a difference in the sub-test profiles of the two groups ($F(9,31)=2.81$, $p=0.016$; see Figure 1). There was much greater variability in performance across the sub-tests amongst the pilots and this was primarily due to weaker scores on tests of digit span (working memory), similarities and picture arrangement (executive function) and digit symbol relative to performance on other intellectual sub-tests.

Table VI. Characteristics of pilots and controls.

Characteristics	Pilots ($n=18$)	Controls ($n=22$)
Mean age (SD) in years	48 (8.8)	46 (10.9)
Mean educational level (SD)	13 (2.3)	12 (2.1)
Mean WAIS-R full scale IQ	119 (10.5)	109 (12.3)

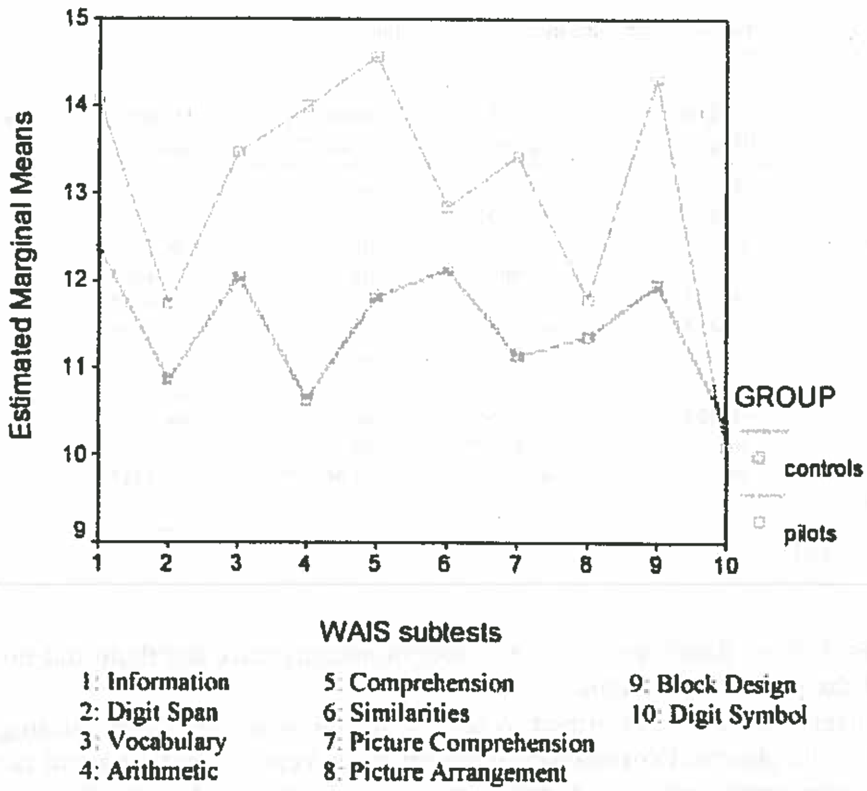

Figure 1. WAIS performance profiles.

Correlations between exposure history (flying hours) and cognitive function. Pearson Product Moment Correlations (or Spearman when appropriate) were used to establish whether there is a relationship between cognitive function and exposure history. It was predicted that performance will worsen with increased exposure; therefore, due to the unidirectional nature of the hypothesis, one-tailed test of significance was used. The number of variables entered into the analysis was kept to a minimum to reduce the risk of Type 1 errors occurring as a result of multiple comparisons. Partial correlations were also performed to control for the potentially confounding effects of age which was associated with both flying hours/years and performance on psychometric tests (see Table VII).

Significant correlations were observed between total number of years spent flying and lowered scores on the following tests: picture arrangement (visual sequencing), the Stroop test of mental flexibility, the trails B test of mental flexibility and a test of verbal memory ($r=-0.442$, $p<0.05$; $\rho=-0.414$, $p<0.05$; $r=0.544$, $p<0.01$; $r=-0.422$, $p<0.05$).

Significant correlations were observed between total number of hours spent flying and lowered scores on the following tests: picture arrangement (visual sequencing), semantic fluency, the trails B test of mental flexibility and three different tests of verbal memory ($r=-0.448$, $p<0.05$; $r=-0.400$, $p<0.05$; $r=0.453$, $p<0.05$; $r=-0.415$, $p<0.05$; $r=-0.530$, $p<0.05$; $r=-0.462$, $p<0.05$).

Lowered scores on tests of semantic fluency, mental flexibility (trails B and Stroop) and mental speed correlated with hours on the BAe 146 ($r=-0.463$, $p<0.05$; $r=0.817$, $p<0.01$; $\rho=-0.557$, $p<0.01$; $r=-0.651$, $p<0.01$). Correlations with hours on the Boeing 757 aircraft were counter-intuitive and indicated improved performance on tests of mental flexibility and mental speed were associated with this variable ($r=-0.565$, $p<0.01$;

Table VII. Correlations between exposure indices and psychometric tests.

Psychometric test	Total flying years	Total flying hours	Hours on Boeing 757	Hours on BAe 146	Number of months since last flight
Digit Span	ns	ns	ns	ns	ns
Picture Arr.	−0.442*	−0.448*	ns	ns	ns
Digit Symbol	ns	ns	ns	ns	ns
Semantic Flu.	ns	−0.400*	ns	−0.463*	ns
Trail B	0.544**	0.453*	−0.565**	0.817**	ns
Stroop	−0.414*	ns	0.420*	−0.557**	ns
Story I	ns	ns	ns	ns	ns
Story D	ns	−0.415*	ns	ns	ns
List I	−0.422*	−0.530*	ns	ns	ns
List D	ns	−0.462*	ns	ns	ns
Mental Speed	ns	ns	0.667**	−0.651**	ns
Motor Speed	ns	ns	ns	ns	ns

* $p<0.05$; ** $p<0.01$.

$\rho=0.420$, $p<0.05$; $r=0.667$, $p<0.01$). Number of months since last flight did not correlate with any of the psychometric data.

Partial correlations were performed to control for the potentially confounding effects of age and all of the observed correlations between hours/years spent flying and performance on psychometric tests were lost. Significant, but counter-intuitive correlations remained between hours spent flying the Boeing 757 aircraft type, mental flexibility and mental speed ($r=-0.4806$, $p<0.03$; $r=0.6293$, $p<0.003$). Significant correlations in the predicted direction remained between the number of hours spent flying the BAe146 aircraft type, mental speed and two tests of mental flexibility ($r=-0.6061$, $p<0.005$; $r=0.7867$, $p<0.0001$; $r=-0.4705$, $p<0.03$).

Discussion and conclusions

This paper presents a case series of 27 pilots who underwent neuropsychological assessment at University College London. To reduce the risk of false positive results, nine pilots with a medical or psychiatric history which might otherwise accounted for any deficits or symptoms identified during assessment were excluded from group analyses of psychometric test data.

Pilots completed an extensive battery of more than 30 neuropsychological tests. There was no evidence of global intellectual decline, language or perceptual deficits in this cohort. Indeed, pilots were intact on the vast majority of tests. However, there was evidence of under-functioning on tests associated with psychomotor speed, executive functioning and attention. Indeed pilots exhibited a different, more variable pattern of performance across intellectual sub-tests than healthy controls (matched for age, gender and years of education but not IQ).

Statistical analyses were carried out to look at the relationship between exposure history and cognitive deficits. A number of significant correlations were observed between exposure variables and verbal memory, executive function and information processing speed. However, when the potentially confounding effects of age weres controlled for, some of these correlations became non-significant.

The exposure indices available in this study were crude and may not be reliable or valid measures of exposure to contaminated air. For example, the pilots in this study had flown a variety of aircraft types over their career history, some of which will not have suffered engine oil leaks, therefore total number of hours or years spent flying may not be a good index of exposure to contaminated air. Even hours spent flying the BAe 146 or Boeing 757 aircraft types may also fail to capture exposure adequately, as exposure will depend on whether a fault occurs in a particular aircraft and some aircraft may be maintained to a higher standard than others. Reporting rate is also unlikely to correlate highly with exposure as a number of factors influence whether aircrew report fume events. However, it may be the case that factors other than exposure to contaminated air are responsible for the cognitive deficits identified in this analysis. Alternative explanations might include medical or psychiatric background, mood disorder/emotional distress, malingering or the general lifestyle of pilots.

Mood disorder, malingering, chance factors

Examiners found little to substantiate the view that the deficits seen in pilots might be secondary to psychological distress, malingering or chance factors. None of the pilots included in the group analysis were suffering from mood disorder and none failed a test of malingering. Working pilots were highly motivated to perform well as they expressed concern that if deficits were identified, they might lose their licence to fly. Furthermore, the profile of deficits seen in this group of pilots is not consistent with malingering and is unlikely to have occurred by chance as pilots were intact on the vast majority of psychometric tests and, when deficits were identified, they were in specific cognitive domains (that is attention, executive function and information processing speed). Malingering and chance factors (for example, regression to the mean) would produce a more random profile of results [17–19]. The pattern of deficits observed in each pilot were similar and consistent and are likely to be real rather than a result of faking or chance factors.

Medical or psychiatric history

Another possibility is that the profile of cognitive deficits identified in this cohort is due to some other medical condition. Although pilots with a medical or psychiatric history (including substance abuse) that might otherwise account for any deficits identified during testing were excluded from the group analysis, the abnormalities detected may be multifactorial so that no obvious, single alternative cause can be established.

The general lifestyle of pilots

Another possibility is that the profile of cognitive deficits identified in this cohort relates to some lifestyle factor, specific to pilots, for example, exposure to radiation, shift working, time changes and jet lag, reduced pressure environment, poor diet, dehydration and humidity. This is considered to be an unlikely explanation for the deficits observed in this cohort, as 50% of the cohort were suspended from or had retired from flying and were no longer subject to these lifestyle factors. Furthermore, the Boeing 757 and BAe 146 aircraft are classified as short haul aircraft. As such they are subject to less radiation and pressurization than long-haul aircraft and pilots are subjected to fewer time zone changes than long haul pilots. However, the best way to confirm whether medical or lifestyle factors are relevant would be to carry out an epidemiological survey of all UK pilots looking at the

incidence, prevalence and severity of physical and psychological symptoms and what if any relationship exists between medical history, the type of aircraft flown and shift patterns pilots are assigned to.

Comparisons with previous research on aircrew exposed to engine oil emissions

General symptoms. With regard to general symptoms, the first paper found concerning ill health following exposure to contaminated air was published by Montgomery et al. [8] in 1977. The paper describes a 34 year old military navigator in a Lockheed C-130 Hercules transport aircraft who experienced acute intoxication following inhalation of vaporized or aerosol synthetic lubricating oil from a contaminated air supply. He reported a gradual onset of headache, nausea, dizziness, vomiting, incoordination and lethargy. By the time the plane could be landed he had difficulty standing. The authors conclude that 'further investigation into the potential hazards from inhalation of synthetic oil fumes ... is definitely warranted'.

Since then a number of papers have been published which describe acute and chronic symptoms of ill health following reported exposure to contaminated air. The term 'Aerotoxic Syndrome' was proposed by Balouet and Winder [20] in 1999 to describe the association of symptoms observed among aircrew exposed to contaminated air. 6c

The symptoms reported in these papers have much in common with those reported by the pilots we examined. For example, in 2002 Winder et al. [3] published the results of a health survey of 68 Australian and US aircrew who flew the BAe 146 and A320 aircraft types: 88% reported the following symptoms occurred after exposure to contaminated air: irritation of eye, nose and throat and respiratory system, gastro-intestinal problems and cognitive impairment. Eighty-two per cent reported that these symptoms persisted for 1 month after exposure and 74% reported symptoms persisted for up to 6 months following exposure.

In 2002, Cox and Michaelis [9] published the results of a health survey of 21 Australian BAe 146 aircrew who reported increased cold-like symptoms, running nose and watery eyes, headaches, skin irritation, fatigue and cognitive impairment, which they associated with flying this particular aircraft type. Forty-seven pe cent thought their symptoms were associated with exposure to contaminated air whilst 37% thought their symptoms were a normal part of working on this particular aircraft type.

In 2003, Michaelis [5] published the findings of a survey of 106 British Boeing 757 pilots who reported a similar constellation of symptoms which they associated with flying the Boeing 757 aircraft type because symptoms increased whilst on duty and improved after duty or on days off work.

A 2005 survey by Harper [10] of 60 commercial aircrew found a close temporal relationship between exposure to fumes and the onset of ill health. Symptoms occurred during flight and a number of people were usually affected concurrently; 45% of symptoms reported were neurological, 22% respiratory, 14% fatigue, 10% gastrointestinal, 5% skin and 3% musculoskeletal. Abnormalities detected during medical investigations include reduction in small airway function, diffusing capacity and gas exchange, nasal and vocal cord polyps, neuropathies, cognitive impairment, abnormal brain scans and evoked potentials.

Cognitive function. With regard to cognitive function, a research team in the US found radiological evidence of organic brain damage in crew complaining of ill health following exposure to contaminated air. Heuser et al. [11] examined 26 North American flight

attendants who presented with a range of disabling physical complaints which had not been thoroughly investigated and had often been trivialized by physicians. Each flight attendant had a neurological examination and a neuropsychological assessment and 12 subjects underwent neuroimaging (PET scans). Neurological abnormalities were detected in 15 flight attendants. Many had impaired balance and coordination and some had developed a movement disorder (postural bilateral tremor). All showed evidence of cognitive impairment. Abnormalities were found in all of the crew who had PET scans, involving imbalance of function between cortical (decrease) and subcortical (increase) areas, frontal (decrease) and occipital (increase) areas; and increased function in some limbic areas, especially the extended amygdale region. Heuser et al. concluded that aircrew, exposed to contaminated air, deserve more medical attention and sophisticated investigations (that is neuroimaging) than is routine and suggested a medical protocol is created which outlines the evaluations that flight personnel should undergo.

A pattern of cognitive deficits, similar to that seen in this study, was described by Coxon [13] in eight Australian aircrew exposed to oil emissions on the BAe 146. Reduced performance on tests of reaction time, information processing speed, fine motor skills and verbal memory were confirmed.

Limitations of this study

This study has several weaknesses, which should be considered when interpreting the results. Weaknesses include sample size, sample bias, limited indices of exposure and the lack of a matched control group.

The number of participants in this study was relatively small and they were a self-selected sample. Therefore, it is unclear how representative they are of the aviation industry as a whole; and the sample size may be too small for associations between indices of exposure and cognitive function, to be detected. It would have been useful to have a control group of pilots who have not been exposed to contaminated air to determine whether the profile of cognitive strengths and weaknesses observed in this cohort is common amongst pilots or related to lifestyle factors.

Limited indices of exposure were available to us other than pilot's self-report. Air quality monitoring systems need to be developed and placed onboard aircraft to determine the incidence of contaminated air events and the nature of any contaminants involved.

Implications for future research

The above limitations make it impossible to establish or rule out a link between the abnormalities detected and exposure to contaminated air. In order to determine whether such a link exists, a large scale epidemiological survey should be undertaken to establish the prevalence of ill health (physical and psychological symptoms) amongst aircrew and relationship, if any, with working practices and exposure to contaminated air.

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ing a continuous pressure of 900-1075 psi. Connect power unit as follows:

a. Reduce hydraulic system pressure to zero.
b. Turn battery switch to BATTERY and close engine hydraulic-fuel shutoff valve switch.
c. Remove necessary cowl from engine and disconnect supply and pressure hoses from engine-driven hydraulic pump (see Figure 2-11).

NOTE

A container should be available to catch hydraulic fluid draining from lines. Take necessary precautions to prevent contamination if fluid is to be reused.

d. Cap hydraulic pump fittings.
e. Connect pump supply hose to hose leading from power unit inlet port and connect pump pressure hose to power unit outlet port.
f. Service hydraulic reservoir and open hydraulic shutoff valve before operating hydraulic power unit.

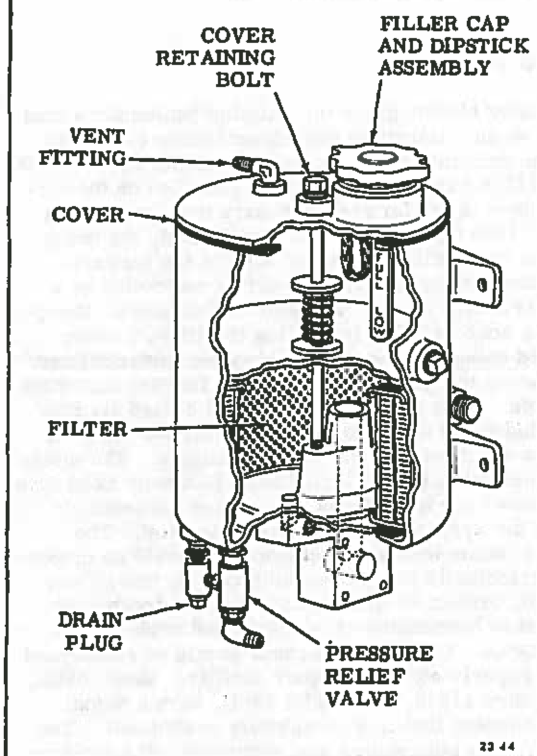

Figure 2-10. Hydraulic Reservoir

NOTE

Always start engine opposite to external hydraulic power unit application on the first run after power unit is used.

ENVIRONMENTAL SYSTEM

The following instructions for servicing the pressurization equipment are intended as a guide for daily flight line maintenance operations only. Procedures other than routine daily maintenance are discussed in Section IX of this manual. Inspect the refrigeration unit oil filler and maintain oil level at top of filler neck. Drain and refill the refrigeration unit with approved oil to top of filler neck as required by the aircraft inspection guide. Inspect inlet air duct for obstructions before each flight (see Figure 2-13 for approved oils).

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OXYGEN SYSTEM

The oxygen cylinder is located in either the aft baggage compartment or the aft fuselage. When fully charged the oxygen cylinder weights 13.38 pounds and contains 22.0 cubic feet of aviator's breathing oxygen at a pressure of 1800 psi.

WARNING

No smoking or open flame of any kind is permitted in or near the aircraft while the oxygen system is on. Keep oil, grease, hydraulic fluid, flammable items, and other foreign material away from oxygen equipment. Dangerous explosions will result if oily fluids contact high pressure oxygen.

Refilling of oxygen cylinders must be accomplished by a reputable oxygen service station using aviator's breathing oxygen. This oxygen is specially dried to remove moisture which could cause corrosion and damage to the system, or which could freeze at low temperatures and render the system useless. The cylinder shutoff valve is equipped with a hex-capped safety device which protects the cylinder from overexpansion of the oxygen in the event of exposure to fire or extreme heat.

CAUTION

Do not attempt to remove the safety device installed in cylinder shutoff valve while the cylinder contains oxygen.

mechanical energy by the turbine. This results in a temperature and pressure drop in the airflow because of expansion. The energy absorbed by the compressor turbine is dissipated in driving the cooling turbine, which increases the airflow through the air-to-air heat exchangers and improves the overall effectiveness of the refrigeration unit. This is accomplished by the fact the compressor turbine wheel is connected to the cooling turbine by a steel shaft that rotates in a pair of matched ball bearings. A wick fed oil system serviced through an oil filler valve assembly, installed on a bracket attached to the top left side of the refigeration unit, lubricates the turbine shaft ball bearings.

SERVICING. Maintain the correct amount of lubricant in the oil filler assembly in accordance with instructions in Section II.

REPAIR. The compressor turbine and cooling turbine assembly rotate at speeds which require the assembly to be critically balanced at the time of assembly. An adjustment as minor as changing the torque on a turbine shaft nut will destroy this delicate balance and require replacement of the cooling turbine. Therefore, repair of the cooling turbine is limited to replacement of hoses and clamps. The turbine may be replaced without removal of the entire refrigeration unit. In the event replacement of the cooling turbine is necessary, drain oil from oil filler assembly prior to removal and do not refill until reinstallation is complete.

WATER SEPARATOR

A water separator, installed on the right side of the refrigeration unit, extracts moisture from the cool air as it leaves the refrigeration unit and prior to entering the cabin area (see Figure 9-2). The water separator contains a dacron cloth coalescer bag that collects the entrained moisture, in the discharge air from the refrigeration unit, into large droplets. These droplets enter a swirl section of the separator where they are removed from the airstream by a collector and discharged overboard through a drain line at fuselage station 272.00. A spring loaded poppet-type relief valve is installed in the aft end of the water separator coalescer bag support. This valve opens to allow air flow through the ends of the coalescer bag in the event the porous walls of the coalescer bag becomes clogged with dirt. A dirty coalescer bag will cause the humidity to raise due to lack of water extraction and consequently decrease air conditioning efficiency. The coalescer bag should be visually inspected and replaced if dirty or worn.

WATER SEPARATOR COALESCER BAG REMOVAL

a. Remove clamps from diverter duct assembly from forward end of the water separator.
b. Disconnect drain hose from separator.
c. Remove band clamp from water separator.
d. Remove forward end of separator and extract coalescer bag.

WATER SEPARATOR COALESCER BAG INSTALLATION

a. Install coalescer bag in forward end of separator.
b. Install forward end of separator and tighten clamp.
c. Connect drain hose to separator.
d. Attach diverter duct assembly to separator and tighten clamps.

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GROUND BLOWER

A ground blower supplies ambient air to the refrigeration unit heat exchangers. The blower assembly is located in the ram air duct at a point immediately forward of the air inlet to the heat exchangers. A continuous duty 28-volt electric motor is used to drive airflow over the heat exchangers below 140 knots in flight. The ground blower will operate when the air conditioning mode selector switch is placed in AUTO or OVERRIDE position and is controlled by the upper duct pressure switch. A ground blower switch under the pilots sub-panel is only used for ground blower maintenance check. This switch shall be placed in the ON position after any ground blower maintenance has been performed (see Figure 9-4).

DEFOG BLOWER

The defog blower gives the existing heated air added force when eliminating fog accumulation caused by sudden descent or high humidity. Model 690A, 11100 thru 11268 has the defog blower installed on the forward side of the forward pressure bulkhead and on 690A 11269 thru 11349, and model 690B, the defog blower is installed on the aft side of the forward pressure bulkhead. The blower is controlled by a manual switch on the overhead switch panel. Defogging is accomplished by pulling the DEFOG lever located under the control panel (when installed) and/or placing the blower switch in the DEFOG BLOWER position. This will force additional heated air into the windshield and side window ducts, warming the windows and causing the fog to dissipate. The motor on model 690A (11100 thru 11268) is a vane axial type that draws air in at the large end and exhausts air out to the system through the smaller end. The blower motor bearings and brushes should be inspected periodically for proper lubrication, and pitted, burned, broken or worn brushes. Maintenance is limited to lubrication of bearings and replacement of brushes. Complete overhaul should be performed by a properly equipped repair facility. Model 690A, 11269 thru 11349, and model 690B, have a defog blower motor that is a completely sealed unit. The blower does not require any servicing. If a malfunction occurs the unit should be removed and replaced. See Section X for electrical diagrams of the system.

REMOVAL AND INSTALLATION

a. Place blower switch in the OFF position.

TROUBLE	PROBABLE CAUSE	REMEDY
Cabin fails to pressurize after takeoff.	Depressurization switch left in the DEPRESS position.	Place depressurization switch to NORMAL position.
	Landing gear ground contact switch malfunctions in the closed position.	Check electrical power on environmental control system circuit. Perform ground operational check and note that both outflow/safety valves open when CABIN DEPRESS circuit breaker is open and depress switch is in the DEPRESS position.
	Three-way solenoid air valve malfunctions in the energized position.	Perform above procedure.
	Cabin altitude preselected to cruise altitude and rate knob selected to a higher rate than aircraft rate-of-climb.	Turn rate knob counterclockwise for a slower rate of cabin change.
	Blocked outflow valve control cabin air filter or orifice.	Perform ground operational check and note if either valve remains open. If neither valve remains open, replace filter and check orifice on outflow valve control.
	Internal malfunction in one or both outflow/safety valves.	Replace filter, clean the orifice in outflow valve control and perform ground operational check. If either valve remains open, remove and replace the valve.
	Internal malfunction in the outflow valve control.	Perform the two preceding remedies. If they are satisfactory, remove and replace outflow valve control.
	Ram air check valve malfunction.	Check and replace if required.
Cabin pressurizes to maximum differential pressure after takeoff.	Loose or damaged pneumatic tube between static atmosphere and outflow valve control.	Inspect and replace all system tubes interconnecting the listed components. Perform ground operational check.
	Loose or damaged pneumatic tubing between three-way solenoid air valve and outflow/safety valves.	Use preceding remedy.
	Internal malfunction in one or both outflow/safety valves.	Disconnect tube at each outflow/safety valve leading to the controller and leak-check the control chamber of each valve. Supply 6.0 inches of water negative pressure; check pressure increase. Pressure increase must not exceed 0.5-inch of water in one minute.
	Malfunction in outflow valve control.	Use preceding remedy. If the preceding remedy checks satisfactory then the trouble is in the outflow valve control. Replace outflow valve control.

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Figure 9-14. Environmental System Troubleshooting (Sheet 1 of 3)

TROUBLE	PROBABLE CAUSE	REMEDY
Cabin altitude decreases below selected altitudes.	Plugged or damaged static atmosphere tube to outflow valve control.	Check and repair static atmosphere tube. Check tube connections. Perform leak-check by disconnecting the tube at the outflow valve control. Supply 6.0 inches of water negative pressure to tube end. Check pressure increase. Pressure increase must not exceed 0.50-inch of water in one minute for the outflow valve. Perform ground operational check.
	Minor leak in tube between outflow valve control and outflow/safety valves.	Perform above procedure.
	Minor leak in outflow valve control.	Check per the above remedy. If the above remedy is satisfactory, replace outflow valve control.
Minimum rates unbalanced; down rate faster than up rate. Other rate operations satisfactory.	Minor leak in outflow valve control.	Perform ground operational check. Remove and replace outflow valve if minimum rate values exceed tolerances.
Higher unpressurized operation before takeoff and after landing.	Three-way solenoid valve malfunctioning of the energized position.	Check electrical power on environmental control system circuit.
	Landing gear ground contact switch malfunctions in the open position.	Perform above procedure.
	Loose or damaged pneumatic tube between three-way solenoid air valve and outflow/safety valves.	Check tube connections. Perform leak-check by disconnecting the tube at solenoid air valve. Supply 6.0 inches of water negative pressure to tubing end. Check pressure increase. Pressure increase shall not exceed 0.5-inch of water in one minute. Replace damaged tube. Perform ground operational check.
Cabin exceeds maximum differential calibrated setting.	Static air tube not reconnected to outflow/safety valves when maintenance was performed.	Check that static air tube on outflow/safety valves are connected securely. Perform ground operational check.
	Loose or damaged pneumatic tubing from port of outflow valve or safety valve to atmosphere.	Inspect, repair or replace tube. Perform ground operational check.
	Internal malfunction in outflow valve.	Perform ground operational check and note the cabin-to-atmosphere pressure differential on each valve to confirm operation.
	Internal malfunction in safety valve.	Same as above procedure.
	Pressure gage defective.	Check and replace gage if required.

Figure 9-14. Environmental System Troubleshooting (Sheet 2 of 3)

TROUBLE	PROBABLE CAUSE	REMEDY
Cabin climbs and descends at a fixed rate regardless of rate selection.	Internal malfunction in outflow valve control.	Perform ground operational check to confirm that outflow valve control has no rate operation.
Cabin rate exceeds the selected rate value during aircraft climb to cruise altitude.	Rate selection on controller set to slow. System on positive differential control.	Increase rate selection or decrease aircraft rate of climb.
	Malfunction in outflow valve control.	Increase rate selection or decrease aircraft rate of climb. Perform ground operational check to confirm that outflow valve control has no rate operation.
Cabin pressure rapidly increases or decreases with reselection of cabin altitude. Rate values greater than those selected, but system will stabilize at the selected cabin altitude.	Malfunction in outflow valve control.	Perform ground operational check to confirm that outflow valve control has no rate operation.
Cabin altitude exceeds selected value.	Loss of airflow into cabin.	Check aircraft inflow system.
	Aircraft altitude exceeded positive differential pressure value.	Adjust higher cabin selection or lower aircraft altitude.
	Internal malfunction in outflow/safety valve.	Perform leak-check by disconnecting the tube at the static air port of outflow/safety valves. Supply 6.0 inches of water negative pressure to the port. Check pressure increase. Pressure increase must not exceed 0.5 inch of water in one minute. Perform ground operational check.
	Internal malfunction in the safety valve.	Same procedure as above.
	Internal malfunction in the outflow valve control.	Perform same procedure as above. If the above procedure is satisfactory, then the outflow valve control should be replaced.

Figure 9-14. Environmental System Troubleshooting (Sheet 3 of 3)

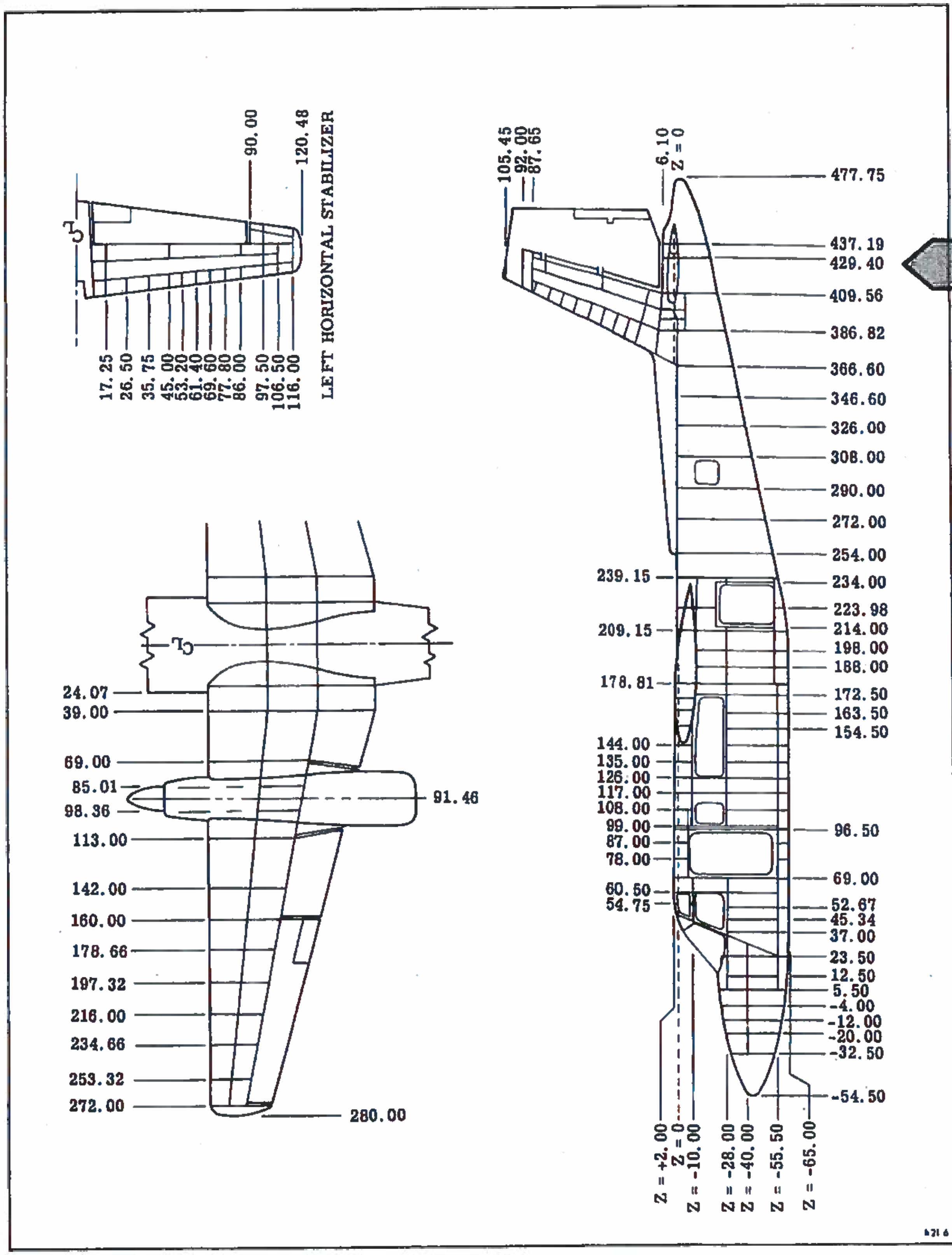

Figure 1-1. Station Diagram

The manner in which the compressed air flow is routed from the jet pump assembly through the refrigeration unit and associated air ducts, determines the temperature of the conditioned air entering the cabin (see Figure 9-3). Cabin pressure is vented from the cabin through the outflow/safety valves as determined by the pressure controller setting.

An electrically operated cooling air blower draws air from the ram air inlet and forces it over the cooling fins of the refrigeration unit primary and secondary heat exchangers for ground cooling and for some phases of inflight air conditioning.

AUTO position of the air conditioning mode selector switch, opens the bleed air valves to the primary jet pumps. The AUTO position also arms the automatic temperature selector to regulate either warm or cool air. The automatic temperature selector rheostat programs the temperature controller for automatic operation of the air conditioning system. If WARM air is selected, the hot air valve opens allowing bleed air and cool air to be mixed and routed direct to the cabin area to maintain a desired temperature. If additional heat is required in either flight or ground operation, the maximum heat or maximum flow/ground cool switch may be placed in either MAX HEAT position (690A, 11100 thru 11120) or MAX FLO position (690A, 11121 thru 11349, and 690B). This opens the auxiliary bleed air valve to supplement the primary jet pumps. Either the MAX HEAT or MAX FLO light in the annunciator panel will be illuminated as long as the auxiliary bleed air valve is open. If COOL air is selected, the hot air valve closes. This directs all bleed air through the heat exchanger and compressor turbine and into the cooling turbine. Cold air from the cooling turbine is then routed through ducting to cool the cabin.

On model 690A, 11100 thru 11120, if additional cooling is required in ground operation below 80 percent rpm, either the maximum heat or maximum flow/ground cool switch may be placed in GND COOL. This opens the direct bleed air bypass valve, allowing high pressure direct engine bleed air to bypass the jet pumps, pass through the refrigeration unit primary and secondary heat exchangers and enter the refrigeration unit compressor turbine.

CAUTION

The automatic temperature selector control must be in the COOL position to prevent overheating of the ducts.

This high temperature direct bleed air drives the cooling turbine at maximum performance providing maximum cooling and air flow to the cabin. The GND COOL light in the annunciator panel will be illuminated as long as the direct bleed air bypass valve is open.

The AUTO position of the air conditioning mode selector switch, also programs the ground blower for automatic operation. The ground blower is used for ground operation, and in flight to supplement the ram air flow at low aircraft speeds.

Placing the air conditioning mode selector switch in OVER-RIDE position, energizes the manual override temperature heat and cool switch. The manual override temperature switch is a momentary heat or cool switch, used to override the automatic system to provide fast temperature changes in the event of malfunctioning temperature sensors. This override temperature switch is also used to maintain cabin temperature in the event of a malfunction in the automatic control system. Placing the override temperature switch in the COOL position, closes the hot air valve, directing all bleed air to the heat exchanger and secondary compressor. Cool air from the refrigeration cooling turbine is then routed to the cabin. Placing the override temperature switch in the HEAT position opens the hot air valve. Hot air enters the plenum and mixes with cool air to maintain desired cabin temperature. It may take up to 30 seconds for valves to open. The OVER-RIDE position of the air conditioning mode selector switch also programs the ground blower for automatic operation. The manual override temperature switch is protected against inadvertent activation by the air condition mode selector switch which must be in the OVER-RIDE position. The OVER-RIDE position of the air conditioning mode selector switch opens the bleed air valves providing bleed air to the primary jet pumps.

OFF/RAM AIR position of the air conditioning mode selector switch deactivates all equipment and the system operates on ram air only. Ram air is then provided for ventilation during unpressurized flight, before and after system operation on the ground and during the engine starting period. If ground blower operation is required while on the ground, the engines should be in operation and the air conditioning mode selector switch placed in either AUTO or OVER-RIDE.

In the event it is necessary to eliminate fogging, noxious fumes or smoke, increase the temperature by placing the automatic temperature selector control in the WARM position, pull the defog lever under the control panel (when installed), and place the defog blower switch located in the overhead switch panel in the DEFOG BLOWER position. This will force heated air into the cockpit and on to side windows and windshield, causing the fog to dissipate. If noxious fumes or smoke enters the aircraft, the bleed select switch may be used to determine which engine is the source. Isolate the engine by placing the bleed select switch to the desired engine. This causes the opposite jet pump bleed air valve to close isolating that engine. Allow at least one minute for the condition to change. If condition persists, place bleed select switch to the opposite engine. If condition clears, continue operation with faulty system isolated. If condition doesn't improve, place air conditioning mode selector switch to OFF/RAM AIR position, place pressurization switch to DEPRESS. If an in-flight engine shutdown becomes necessary,

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the bleed select switch should be used to isolate the feathered engine.

PRINCIPLES OF OPERATION

During operation of the normal pressurization and air conditioning system ambient air enters the ram air duct under ram pressure. The majority of the ram air passes over the primary and secondary heat exchanger cooling fins and is exhausted overboard through the exhaust port, in the bottom of the fuselage. Air for the cabin is drawn from the ram air plenum by the primary jet pumps. High-pressure high-temperature, low-flow air (engine bleed air) is mixed with ram air and converted to a low-pressure, high-flow, lower-temperature air stream by the jet pump action. This air flow is used for heating, cooling and pressurization. When the temperature control system demands maximum cooling, the hot air valve is closed and all air is routed through the refrigeration unit. If ambient temperature is moderate and neither full heating nor full cooling is required, the hot air valve is modulated by the temperature controller to maintain the selected temperature.

AIR SUPPLY AND DISTRIBUTION

Ram air enters the flush inlet scoop, installed on the top centerline of the aft fuselage and is routed to the jet pump assembly, heat exchangers and the air inlet side of the air plenum unit (see Figure 9-3). A drain line that extends from the lowest part of the inlet air scoop through the lower fuselage skin prevents water from entering the inlet air duct when the aircraft is parked. Ram air from the inlet air scoop is routed through the main air duct over the external surfaces of the air-to-air heat exchangers before being dumped overboard, through the ram air exhaust in the bottom of the fuselage. Compressed air from the jet pumps is routed through the air-to-air heat exchangers to further lower its temperature before it is directed into the aircraft cabin. A ground blower, installed in the ram air duct draws ambient air into the duct for ground operation and augments the ram air input over the heat exchangers as required when flying at low airspeeds. A mechanical air inlet check valve installed in the inlet duct to the air transition unit is provided to shut off ram air flow to the transition unit unless ram air ventilation is selected. When the bleed air shutoff valves are closed the mechanical air inlet check valve is open; therefore a portion of the ram air is directed through the transition unit to the cabin area. Efficient operation of the environmental system depends on the availability and proper routing of an adequate air supply to all sub-systems and components; therefore air flow control valves, outflow valves, air ducts, interconnecting duct gaskets and clamps must be properly maintained to obtain effective cabin pressurization and air conditioning.

ENVIRONMENTAL SYSTEM COMPONENTS

The purpose, operating principles, and maintenance requirements of environment system components are outlined in the following paragraphs.

ENVIRONMENTAL SYSTEM JET PUMP ASSEMBLY

Compressed air for operation of the environmental system is provided by the jet pump assembly. The jet pump assembly consisting of two primary jet pumps and one auxiliary jet pump is installed in the aft fuselage on the right side of the aircraft. Engine bleed air routed from the aircraft engines provides motivating power for the jet pumps, which draw ambient air from the ram air plenum. The high-pressure, high-temperature, low-flow engine bleed air is mixed with the ambient air and converted to a low-pressure, high-flow, lower-temperature air by jet pump action to provide the air flow required for operation of the environmental system. Mixed air from the jet pumps flows into a check valved air duct which has dual outlets for routing air to the primary heat exchanger of the refrigeration unit or to the air plenum unit according to the demands for cabin temperature set by the environmental control selector. Operation of the jet pump assembly is controlled by three electrically driven bleed air shutoff valves, installed in the engine bleed air lines, which are opened or closed to control engine bleed air flow to the primary and/or auxiliary jet pumps. The jet pump assembly is operating during all phases of ground and flight operation of the environmental system except when using ram air for ventilation.

REFRIGERATION UNIT

The air cycle refrigeration unit consists of a primary heat exchanger, secondary heat exchanger and a two wheel cooling turbine driven by the output of the primary heat exchanger. Compressed air from the jet pumps flow through tubes of the primary heat exchanger, where the temperature of the air is reduced to within a few degrees of the ram air temperature by transfer of heat through the primary heat exchanger. The air is compressed by the refrigeration unit compressor turbine and then flows through the secondary heat exchanger where it is again cooled to remove the heat gained during the second phase of compression. From the secondary heat exchanger the compressed air is further cooled by expansion as it flows out of the cooling turbine, thru the water separator (690B) and into the air transition unit to the cabin.

COOLING TURBINE. The cooling turbine, in conjunction with the air-to-air heat exchangers, is provided to reduce the compressed air temperature before it is routed to the cabin. Operation of the cooling unit is based on the conversion of kinetic energy of the air to

mechanical energy by the turbine. This results in a temperature and pressure drop in the airflow because of expansion. The energy absorbed by the compressor turbine is dissipated in driving the cooling turbine, which increases the airflow through the air-to-air heat exchangers and improves the overall effectiveness of the refrigeration unit. This is accomplished by the fact the compressor turbine wheel is connected to the cooling turbine by a steel shaft that rotates in a pair of matched ball bearings. A wick fed oil system serviced through an oil filler valve assembly, installed on a bracket attached to the top left side of the refigeration unit, lubricates the turbine shaft ball bearings.

SERVICING. Maintain the correct amount of lubricant in the oil filler assembly in accordance with instructions in Section II.

REPAIR. The compressor turbine and cooling turbine assembly rotate at speeds which require the assembly to be critically balanced at the time of assembly. An adjustment as minor as changing the torque on a turbine shaft nut will destroy this delicate balance and require replacement of the cooling turbine. Therefore, repair of the cooling turbine is limited to replacement of hoses and clamps. The turbine may be replaced without removal of the entire refrigeration unit. In the event replacement of the cooling turbine is necessary, drain oil from oil filler assembly prior to removal and do not refill until reinstallation is complete.

WATER SEPARATOR

A water separator, installed on the right side of the refrigeration unit, extracts moisture from the cool air as it leaves the refrigeration unit and prior to entering the cabin area (see Figure 9-2). The water separator contains a dacron cloth coalescer bag that collects the entrained moisture, in the discharge air from the refrigeration unit, into large droplets. These droplets enter a swirl section of the separator where they are removed from the airstream by a collector and discharged overboard through a drain line at fuselage station 272.00. A spring loaded poppet-type relief valve is installed in the aft end of the water separator coalescer bag support. This valve opens to allow air flow through the ends of the coalescer bag in the event the porous walls of the coalescer bag becomes clogged with dirt. A dirty coalescer bag will cause the humidity to raise due to lack of water extraction and consequently decrease air conditioning efficiency. The coalescer bag should be visually inspected and replaced if dirty or worn.

WATER SEPARATOR COALESCER BAG REMOVAL

a. Remove clamps from diverter duct assembly from forward end of the water separator.
b. Disconnect drain hose from separator.
c. Remove band clamp from water separator.
d. Remove forward end of separator and extract coalescer bag.

WATER SEPARATOR COALESCER BAG INSTALLATION

a. Install coalescer bag in forward end of separator.
b. Install forward end of separator and tighten clamp.
c. Connect drain hose to separator.
d. Attach diverter duct assembly to separator and tighten clamps.

GROUND BLOWER

A ground blower supplies ambient air to the refrigeration unit heat exchangers. The blower assembly is located in the ram air duct at a point immediately forward of the air inlet to the heat exchangers. A continuous duty 28-volt electric motor is used to drive airflow over the heat exchangers below 140 knots in flight. The ground blower will operate when the air conditioning mode selector switch is placed in AUTO or OVERRIDE position and is controlled by the upper duct pressure switch. A ground blower switch under the pilots sub-panel is only used for ground blower maintenance check. This switch shall be placed in the ON position after any ground blower maintenance has been performed (see Figure 9-4).

DEFOG BLOWER

The defog blower gives the existing heated air added force when eliminating fog accumulation caused by sudden descent or high humidity. Model 690A, 11100 thru 11268 has the defog blower installed on the forward side of the forward pressure bulkhead and on 690A 11269 thru 11349, and model 690B, the defog blower is installed on the aft side of the forward pressure bulkhead. The blower is controlled by a manual switch on the overhead switch panel. Defogging is accomplished by pulling the DEFOG lever located under the control panel (when installed) and/or placing the blower switch in the DEFOG BLOWER position. This will force additional heated air into the windshield and side window ducts, warming the windows and causing the fog to dissipate. The motor on model 690A (11100 thru 11268) is a vane axial type that draws air in at the large end and exhausts air out to the system through the smaller end. The blower motor bearings and brushes should be inspected periodically for proper lubrication, and pitted, burned, broken or worn brushes. Maintenance is limited to lubrication of bearings and replacement of brushes. Complete overhaul should be performed by a properly equipped repair facility. Model 690A, 11269 thru 11349, and model 690B, have a defog blower motor that is a completely sealed unit. The blower does not require any servicing. If a malfunction occurs the unit should be removed and replaced. See Section X for electrical diagrams of the system.

REMOVAL AND INSTALLATION

a. Place blower switch in the OFF position.

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little bit of relief here and then we'll come right back.

(Recess was taken.)

Q. (By Mr. Byrd) So, Mr. Probst, when we -- we were talking about -- you said it was an ACM, you said it was in the airplane, we don't know the serial number, but we're calling it the original one. And a new one that was an overhaul, but service unit, that Serial No. 0335.

You testified that you exchanged the original ACM with -- and by the way, I know from looking at the service records, this was -- there had been a lot of ACMs in this machine, in this airplane. They kind of get failed, and then they get -- you put a new one in or an overhauled one in periodically.

A. Yes, I think that the one that was in there originally was only there about three or four years. It was changed right before we got the airplane. I believe that's right. I remember seeing something about it in the log entry.

Q. I want you to -- I want to draw your attention to the documents that says Maintenance Logs Fairchild Controls, 6/21/11.

A. Uh-huh.

Q. You testified that you believe this page

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represents -- it goes with the overhauled machine you're getting, the 335 machine. And it says in this document that the condition as received was no visual damage. No, that's the 335 machine.

A. Yes, it so -- so it says right on the document.

Q. Okay.

A. Fourth number down there, 335.

Q. The reason for removal was overhaul evaluation?

A. Uh-huh.

Q. And then it says the cause of failure was contact damage between the housing studying assembly and the turbine wheel.

A. Yes.

Q. There is evidence of oil leakage from both the turbine side and the impeller side of the rotor.

A. Okay.

Q. Okay. So, what you described to us in the original machine was, in fact, contact between the turbine wheel and the housing assembly, right?

A. Uh-huh.

Q. So, the problem that this 335 machine had, would you agree, was the same problem that your original machine had?

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A. I would venture to guess it's the same problem they all have when they go in to be repaired.

Q. So consistent with that, doesn't it make sense that there would have been oil leakage from both the turbine side and the propeller side of the rotor in the original ACM that was in the aircraft on May 31st, 2011?

A. If there were any evidence of it, yes. But there was no evidence of it anywhere.

Q. But you have testified the failure of the original machine is consistent with the description of the failure in the replacement part you got?

A. The reason we changed it, yes.

Q. Okay.

A. It didn't actually fail. The part is still working.

Q. But the turbine rotor was --

A. It had a --

Q. -- off track?

A. It had a -- yeah, it had a little scrape on it. Yes, that's true.

Q. And in your inspection -- did you inspect it, the original ACM?

A. Yes, I was standing right there and inspected it.

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Q. And did you get a report back from Fairchild on the maintenance of the original ACM?

A. No, that would not normally happen.

Q. So, is it like a core that you exchange --

A. Right, core. Uh-huh.

Q. If we contacted Fairchild, I guess, it's feasible we might be able to get a report on what they did to that original one.

A. Yes.

Q. Or what they did --

A. Or go back in the logbook and find the -- when it was installed originally, which is not that far back. It can be done, yes.

Q. Okay. I'm going now to August 1st, 2011. This is in the package, and we're going to -- we're going to make an exhibit out of this package of pictures of maintenance logs called Deposition of John Probst.

MR. BYRD: If there's no objections, they're just picture of the maintenance log. And I don't know what the next exhibit number is, but you can go ahead and mark one of those.

Q. (By Mr. Byrd) August 1st, 2011, do you see an entry, airframe total time is 11975 at that

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FOIL AIR/GAS BEARING TECHNOLOGY ~ AN OVERVIEW

Giri L. Agrawal
R&D Dynamics Corporation
Bloomfield, CT 06002

ABSTRACT

This paper summarizes the chronological progress of foil air bearings for turbomachinery during the last 25 years. Descriptions of various machines which are in production are provided. The foil bearing air cycle machine on the 747 aircraft has demonstrated an MTBF (mean time between failure) in excess of 100,000 hours. Many advantages of foil air bearings are noted. Various designs of foil air bearings presently in use and their relative merits are described. Analytical methods, their limitations, and their relationships with test results are noted. Descriptions of various machines built and tested in process fluids being gases, other than air, and cryogenic liquids are described. Conclusions are drawn that various high speed turbomachines including high temperature applications can be designed and developed using foil air bearings which will increase efficiency and reduce cost of these machines.

INTRODUCTION

Foil air bearings have made significant progress during the last 25 years. Reliability of many high speed turbomachines with foil bearings has increased over tenfold compared to those with rolling element bearings. A high speed rotating machine called Air Cycle Machine (ACM) is the heart of the Environmental Control System (ECS) used on aircraft to manage cooling, heating and pressurization of the aircraft. Today, ACM for almost every new ECS system on military and civil aircraft and on many ground vehicles use foil air bearings. Old ECS systems with rolling element bearings are being converted to foil air bearings. The F-16 aircraft ACM used rolling element bearings from 1974 to 1982, but all aircraft built since 1982 use foil air bearings. The 747 aircraft ACM used rolling element bearings from 1970 to 1988. All aircraft built since 1988 have foil air bearings. ECS on the older model 737 aircraft have rolling element bearings, whereas ECS on new 737 use foil air bearings. Many machines with working fluids other than air, such as helium, xenon, refrigerants, liquid oxygen and liquid nitrogen, have been built and successfully tested.

WHY FOIL BEARINGS?

The use of foil bearings in turbomachinery has several advantages.

<u>Higher Reliability</u> - Foil bearing machines are more reliable because there are fewer parts necessary to support the rotative assembly and there is no lubrication needed to feed the system. When the machine is in operation, the air/gas film between the bearing and the shaft protects the bearing foils from wear. The bearing surface is in contact with the shaft only when the machine starts and stops. During this time, a coating on the foils limits the wear.

<u>No Scheduled Maintenance</u> - Since there is no oil lubrication system in machines that use foil bearings, there is never a need to check and replace the lubricant. This results in lower operating costs.

<u>Soft Failure</u> - Because of the low clearances and tolerances inherent in foil bearing design and assembly, if a bearing failure does occur, the bearing foils restrain the shaft assembly from excessive movement. As a result, the damage is most often confined to the bearings and shaft surfaces. The shaft may be used as is or can be repaired. Damage to the other hardware, if any, is minimal and repairable during overhaul.

<u>Environmental Durability</u> - Foil bearings can handle severe environmental conditions such as sand and dust ingestion. Larger

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particles do not enter into the bearing flow path because of a reversed pitot design at the cooling flow inlet and smaller particles are continually flushed out of the bearings by the cooling flow. This ability to withstand contamination eliminates the need for filters in the airflow.

High Speed Operation - Compressor and turbine rotors have better aerodynamic efficiency at higher speeds. Foil bearings allow these machines to operate at the higher speeds without any limitation as with ball bearings. In fact, due to the hydrodynamic action, they have a higher load capacity as the speed increases.

Low and High Temperature Capabilities - Many oil lubricants cannot operate at very high temperatures without breaking down. At low temperature, oil lubricants can become too viscous to operate effectively. Foil bearings, however, operate efficiently at severely high temperatures, as well as at cryogenic temperatures.

Process Fluid Operations - Foil bearings have been operated in process fluids other than air such as helium, xenon, refrigerants, liquid oxygen and liquid nitrogen. For applications in vapor cycles, the refrigerant can be used to cool and support the foil bearings without the need for oil lubricants that can contaminate the system and reduce efficiency.

HISTORY

Garrett AiResearch (now Allied Signal) has done the pioneering work on foil air bearings. Several laboratory and prototype machines were built in the mid 60's. The first production ACM using foil air bearings was designed and developed for the DC-10 ECS system in 1969. Field experience proved that the unit was far more reliable then previous 727 ball bearing units. Further research and laboratory testing to increase load capacity and damping continued. In 1972, a 125 kw turbo-alternator-compressor (TAC) supported on foil bearings was built by AiResearch for NASA Lewis, which worked well. In 1974, under pressure from the Navy to increase the reliability of the A7E air cycle machine, AiResearch converted existing ball bearing machines to foil bearing machines on three A7E aircraft. These aircraft were flown by the Navy off the Coral Sea during the Vietnam War for evacuation of Americans from South Vietnam. These units worked extremely well and proved to be much more reliable than previous ball bearing units. As a result, after Vietnam was over, the Navy gave a contract to AiResearch to convert the entire fleet of A7E to foil bearing units. This program gave high confidence to AiResearch management in foil bearing technology even for a military aircraft. In 1976, when the F-18 program was launched by Northrop, AiResearch decided to proceed with foil air bearings from the start. The unit successfully passed vibration and shock load testing. This was the first military unit with foil air bearings to go into production.

In 1978, AiResearch developed a small foil air bearing supported ACM for the commuter plane Cessna-550. This unit since then is also used on other aircraft e.g. EMB-120, ATR-42, ATR-72 and others. In 1979, a new commercial aircraft 767/757 was launched by Boeing. By now the success of foil air bearings was well known; hence Boeing required that ECS on 767/757 use foil air bearings. AiResearch successfully developed a foil air bearing supported ACM for 767/757. Based on the successful testing, they won the contract and went into production. In 1979 AiResearch developed a foil air bearings supported ACM for Navy F-14 aircraft which was also flight tested on Air Force F-15 aircraft with some modifications. Later AiResearch, by making necessary modifications, used existing machines on various other ECS systems. They also developed a small foil air bearing supported machine for the M-1 tank.

While substantial advancement in foil air bearing technology was being made by AiResearch in the 70's, their competitor Hamilton Standard started lagging behind in ECS business. At the same time, Mechanical Technology Inc. (MTI), a research and development company, came up with their own concept of a foil bearing design called Hydresil. Hamilton signed a contract with MTI to use Hydresil bearings. Hydresil had comparable load capacity, but had low damping. Several ACM with Hydresil bearings were flight tested by Hamilton on 747 aircraft from 1975 to 1979. During flight testing those units lasted only four hours to fifty hours. In 1979, Hamilton launched their own program for foil bearing research. They came up with their own design concept and patented it. In 1982, Hamilton successfully flight tested a foil bearing ACM based on their own foil bearing design on F-16 aircraft. The same machine with minor changes went into production for B-1B aircraft and B-2 aircraft. Later the same machine was successfully flight tested on two F-18 aircraft. Based on successful flight test experience, the Navy qualified the machine for the F-18 without formal qualification testing. Hamilton also developed, qualified and produced a machine for L-1011 aircraft. Under pressure from various airlines, Boeing adopted the same machine with some changes for 747-400 aircraft which went into production in 1988. This machine has shown MTBF (mean time between failure) of over 100,000 hours. Between 1983 and 1988, Hamilton developed several other prototype machines supported on foil air bearings. In 1991, Hamilton developed, qualified and started producing a machine for SAAB 2000 aircraft. The same machine is being used for EMB-145 aircraft.

In 1993, Hamilton developed, qualified and started producing the world's first four-wheel ACM supported on foil air bearings for 777 aircraft. The unit passed 36,000 start-stop cycle to simulate a 30 year life.

Various other companies such as Sunstrand, British Aerospace, ABG-Semca (France) and Tupolev (Russia) have done limited work on foil air bearing technology.

FOIL BEARING TECHNOLOGY

The principle of an air or gas bearing is simple. As shown in Fig. 1, when two surfaces form a wedge, and one surface moves relative to the other surface, pressure is generated between the surfaces due to the hydrodynamic action of the fluid which carries load.

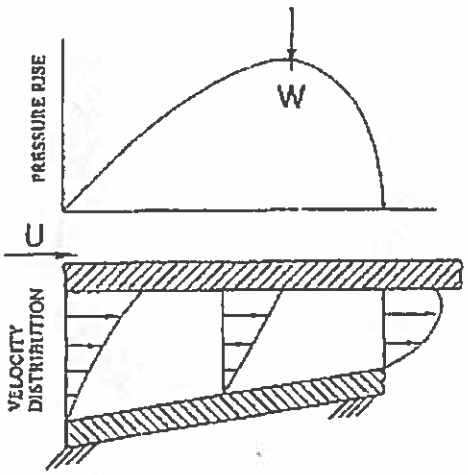

Fig. 1: Principle of an Air Bearing

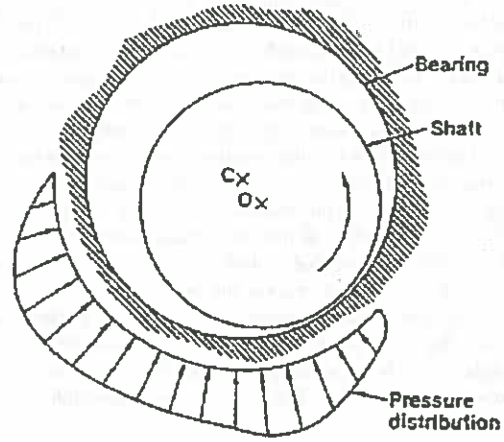

Fig. 2: Hydrodynamic Pressure Generation

Journal Bearing

In a journal bearing, the shaft deflects and a wedge is formed due to the eccentricity between the shaft center and the bearing center. The resulting hydrodynamic pressure generation is shown in Fig. 2. Even though, the principle of an air bearing is simple, application is complex. Usually running radial clearance between the shaft and the bearing is less than 0.0005 inch for a 2 inch diameter shaft running at 36,000 rpm. But the shaft growth due to temperature and centrifugal force could be 0.0020 in. Hence a bearing can not be made to work at various speeds and temperatures. In addition, damping is required to suppress any whirl instability, and there could be misalignment between various rotating parts and stationary parts. These problems are resolved by foil bearings. While stationary, there is a small amount of preload between the shaft and the bearing. As the shaft turns, a hydrodynamic pressure is generated, which pushes the foils away from the shaft and the shaft becomes completely airborne. This phenomenon occurs instantly during start-up at a very low speed. When the shaft is airborne, friction loss due to shaft rotation is very small. As the shaft grows, the foils get pushed further away keeping the film clearance relatively constant. In addition, foils provide coulomb damping due to relative sliding, which is essential for stability of the machine. Various concepts of foil bearings have been tested.

The Multipad concept is shown in Fig. 3, which has been pursued by AiResearch since the days of the DC-10. Multiple pads form an iris and provide a preload when the shaft is not running. During starting, the iris expands and a cushion of air is formed between the bearing and the shaft. Later versions such as for 767/757 have a supportive spring behind each pad which increases the load capacity significantly. The top foil is coated with Teflon-S or a polyimide coating to provide lubricity during starts and stops.

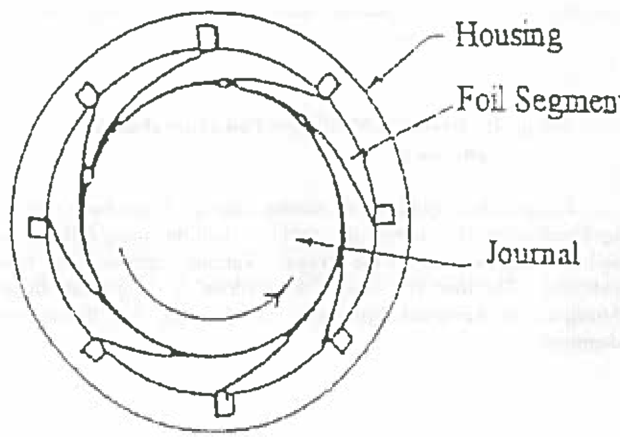

Fig. 3: Multipad Foil Journal Bearing Schematic

Figure 4 is a Reversed Multilayer journal bearing concept which has been pursued by Hamilton Standard in 747, B-1B, B-2, SAAB-2000, 777 and other aircraft. The single corrugated (bump) foil which has a bilinear spring characteristic is restrained in an axial keyway in the outer shell along one edge. The intermediate and top foils are attached to a key along one edge and are wound in opposite directions. The top foil has a thin coating which provides lubricity during startup and shutdown. As the shaft rotates, a wedge is formed due to the radial displacements of the shaft. Hydrodynamic action draws the working gas into the wedge where it is locally compressed. The corrugated foil acts as a spring which accommodates expansion, excursions and any misalignment. It also provides a flow path for the cooling air to remove parasitic heat from the bearing. In the Reversed Multilayer foil bearing, the adjacent foils move in opposite directions. The net result is that relative movement is additive, which in turn produces high coulomb damping.

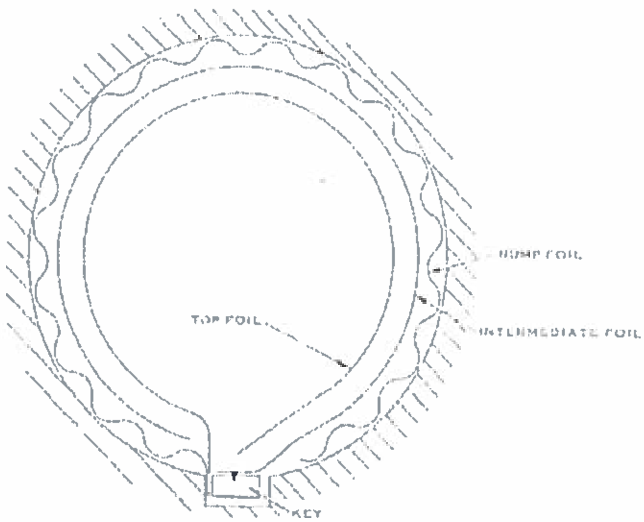

Fig. 4: Reversed Multilayer Foil Journal Bearing Schematic

Figure 5 is a Hydresil foil journal bearing. It has been pursued by Mechanical Technology Inc. (MTI). Both the bump foil and the foil are spot welded to the sleeve. Various versions have been patented. The load capacity of the Hydresil is comparable to the Multipad or Reversed Multilayer foil bearing, but it has low damping.

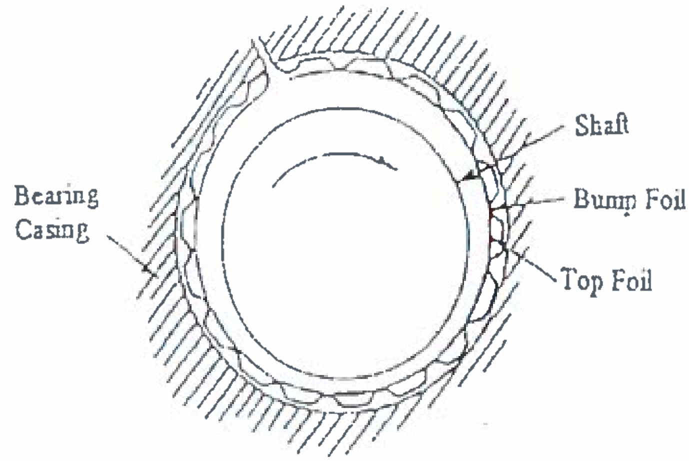

Fig. 5: Hydresil Foil Journal Bearing Schematic

The damping characteristic of three types of bearings is shown in Fig. 6, where orbits are shown when 27 lbs. of shock load is applied to a 2 inch diameter shaft rotating at 36,000 rpm. It is obvious that the Reversed Multilayer concept is the most stable and it is least affected by shock loads.

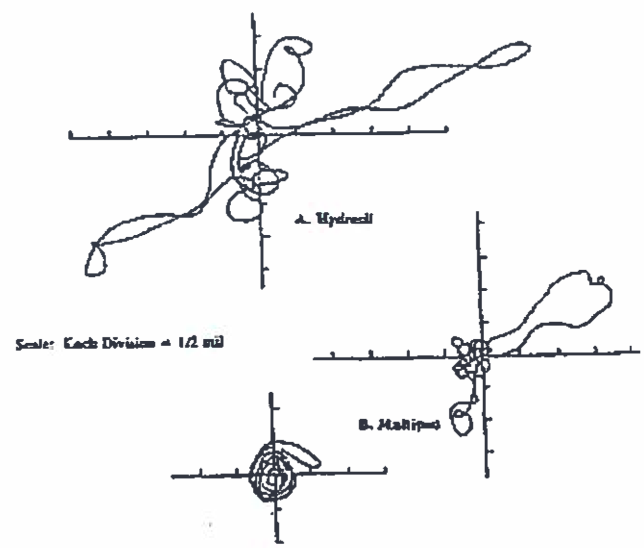

Fig. 6: Orbits of Various Foil Journal Bearings under 27 lbs. of Shock Load

Even though Reversed Multilayer concept has high damping, the foils have a tendency to protrude like a telescope during assembly. In addition, manufacturing is costly because all bends

near the keyway have tight tolerances. A new concept called Reversed Multipad shown in Fig. 7 has been patented by R&D Dynamics Corporation. It has benefits of both Multipad and Reversed Multilayer designs. It has high damping as well as it requires low preload. Lower preload makes the machine start at a lower torque. Due to multipad design, the tolerances are not tight.

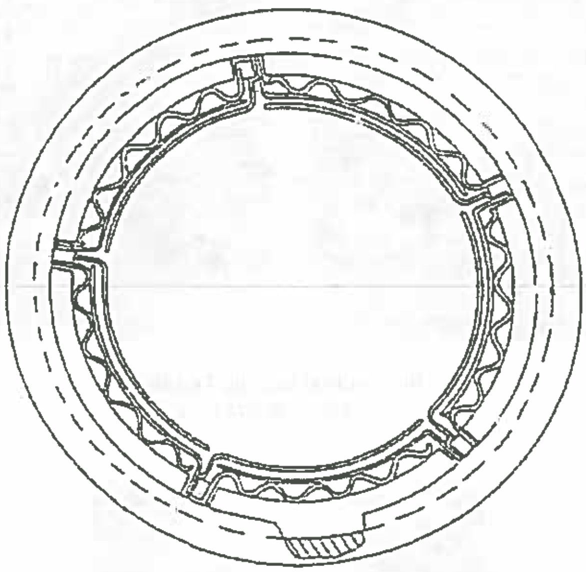

Fig. 7: Reversed Multipad Foil Journal Bearing Schematic

Thrust Bearings

Thrust bearings withstand axial loads in a rotating machinery. They work on the same hydrodynamic principle as journal bearings shown in Fig. 1. In a journal bearing the wedge action comes from eccentricity between the center of the rotating shaft and the center of the bearing itself, whereas in a thrust bearing the wedge is built in taking into account any deflection due the axial load.

A radial spring type thrust bearing is shown in Fig. 8. It was invented by AiResearch and has been followed since 1970 when first used for the DC-10. There are multiple radial springs which transfer the load to the housing. Foils between the springs deflect under pressure forming the wedge required for the hydrodynamic action. During the last 20 years many versions of the same design, usually for the manufacturing reasons mostly by AiResearch, have been used. In some designs instead of a separate spring being spot welded to the main bearing plate, it is formed by chemical etching out of the bearing plate. It reduces manufacturing cost, but somewhat compromises performance in some instances.

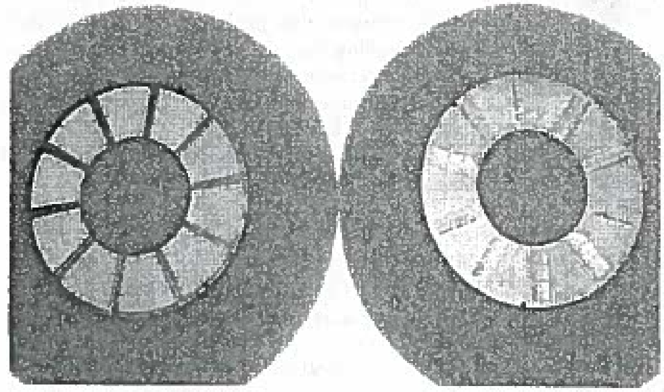

Fig. 8: Radial Spring Foil Thrust Bearing

A dual spring thrust bearing is shown in Fig. 9. It was invented by Hamilton Standard. In this concept the bearing consists of two washer shaped plates similar to radial spring bearings. The coated pads, welded to the top plate, are supported on stiff bump foil springs to optimize the wedge shape required for load capacity and lift-off. The bottom plate has several softer bump foil springs welded to it, required to optimize the overall spring rate and damping of the bearing. The dual spring rate thrust bearings have approximately 15% higher load capacity than the radial spring bearings, but they are more expensive to manufacture.

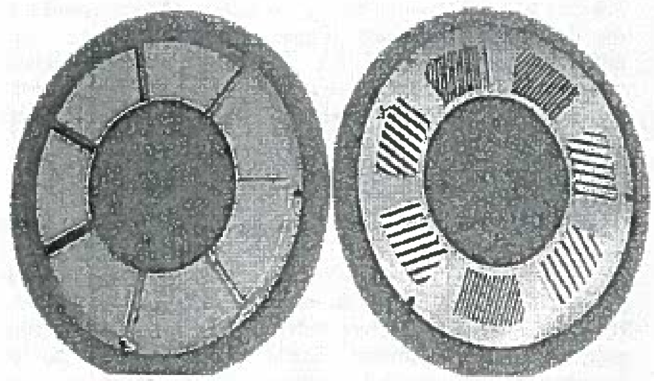

Fig. 9: Dual Spring Foil Thrust Bearing

Coatings

Both journal and thrust bearings apply a small amount of preload on the shaft when the machine is not running. The foil face which is touching the shaft is coated for lubricity during startup and shutdown. A typical DC-10, machine which runs at 48,000 rpm, is fully airborne at about 2,000 rpm. Several foil coatings are used. Most commercial aircraft use Teflon-S made by DuPont which is

good up to 475°F. Most military aircraft ACM use a polyimide coating, whose basic research was performed by NASA Lewis. Both AiResearch and Hamilton have modified the basic formula and the application process to suit their needs. The coating is good up to 700°F. Extensive high temperature coating research has been performed, mostly by NASA Lewis, Air Force Wright Laboratory, AiResearch (Phoenix Division) and Mechanical Technology Inc. A partial list of various coatings, which have been considered, is given below:

Coating	Process
FOIL:	
BN/Pt, BN/Pd	Electrophoretic Deposition
BN/Pt	Chemical Vapor Infiltration
BN/SiO_2, BN/ZrO_2	Sol Gel
BN/Ni-Cr, ZrO_2/Ni-Cr	Mechanical Alloying
BN/Ni	Electroless Deposition
Cr_2O_3	Sputtering
TiC	Sputtering
Al_2O_3	Sputtering
TiN	Sputtering
Tribaloy-400	Sputtering
JOURNAL:	
NASA PS212	Plasma Spray
KAMAN DES	Chemically Adherent
TiAlN/TiAl	Sputtering
WC-9Co	D-Gun
Cr_2O_3-40Cr	D-Gun

Analysis and Testing

The analysis of foil air bearings requires simultaneous solutions or iteration methods to solve foil elasticity equations and fluid hydrodynamic equations. Foil elasticity equations are nonlinear and involves large deformation theory. A foil can deform as much as five times its own thickness. Hence most finite element or finite difference methods, do not provide satisfactory results. Hydrodynamic equations are nonlinear Reynolds' equations with continuously changing boundary conditions. Many papers analyzing foil bearings have been published. In some papers, predicted results vary as much as 500% from the actual test results. What seems to work and provide reasonable results are semi-empirical methods. Sufficient test data are collected by varying geometrical parameters and test parameters of the bearing. Results are correlated using a multiple regression method. Then a model is prepared using coefficients of the multiple regression analysis. Hydrodynamic equations are solved using the preferred final geometry. Then an inverse method is used to design the foil geometry in the unloaded position. In the above described procedure, the complex problem is decoupled into many simple problems using both analytical methods and the test results.

The above described approach has been used both by AiResearch (Los Angeles) and Hamilton Standard to design and develop successfully many foil air bearing machines which are flying today. Others have taken more conventional approach and have not succeeded. Design of the machine parameters such as static and dynamic loads, critical speed, thrust loads, rotor clearance, seals, cooling flow etc. must be correlated with the design of the foil air bearings.

A satisfactory design method requires reliable test data. Successful test rigs to test journal bearings, thrust bearings and coatings have been designed and developed. Typical rigs presently being used at R&D Dynamics Corporation are shown in Figs. 10, 11 and 12.

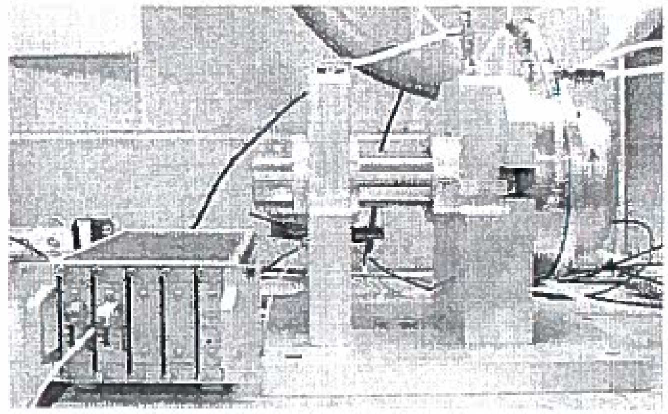

Fig. 10: Journal Bearing Test Rig
(R&D Dynamics Corp.)

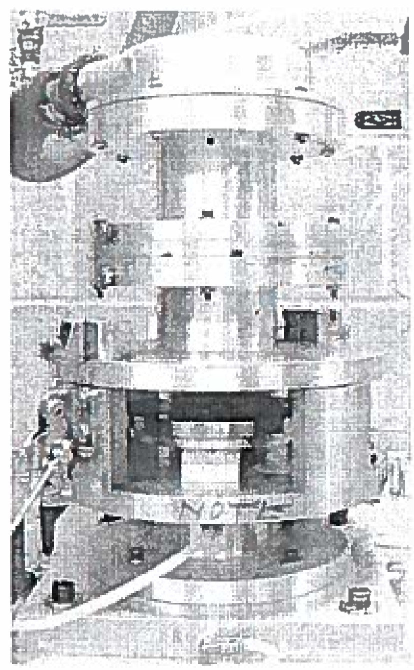

Fig. 11: Thrust Bearing Test Rig
(R&D Dynamics Corp.)

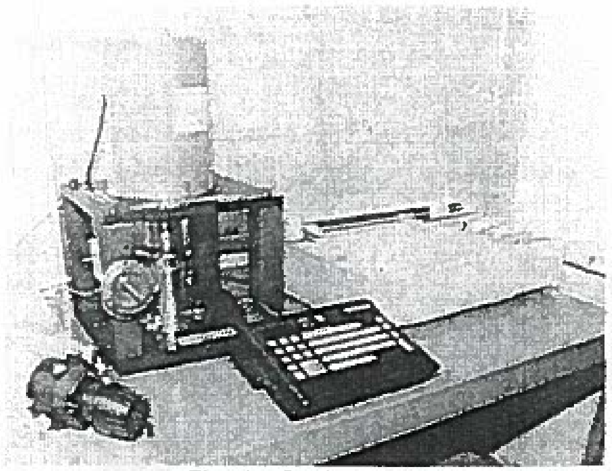

Fig. 12: **Coating Wear Test Rig**
(R&D Dynamics Corp.)

APPLICATIONS

DC-10 - The DC-10 was the first production foil air bearing machine. It was designed and developed by AiResearch and went into production in 1970. The same machine is also used for Airbus A-300. A photograph of the machine is shown in Fig. 13. The rotating assembly has three rotors: a turbine, a compressor and a fan. The machine runs at 48,000 rpm. To date, over 80 million hours have been accumulated on this machine.

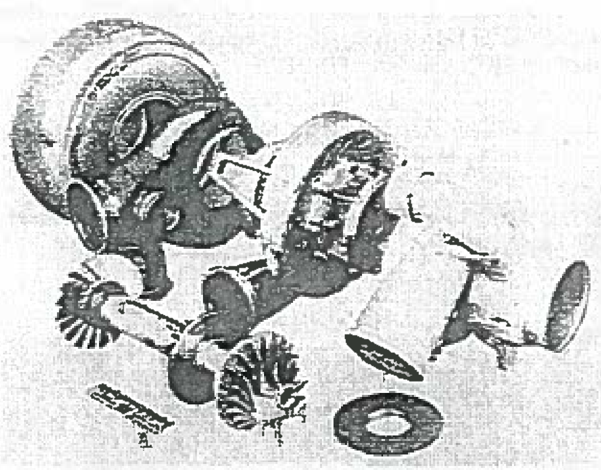

Fig. 13: DC-10 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

F-18 - The F-18 is the first military production machine after successful modifications of the A7E machine from ball bearings to air bearings. The F-18 machine was designed and developed by AiResearch in 1976. A cross section of the machine is shown in Fig. 14. It has two rotors: a turbine and a compressor. The machine runs at about 95,000 rpm.

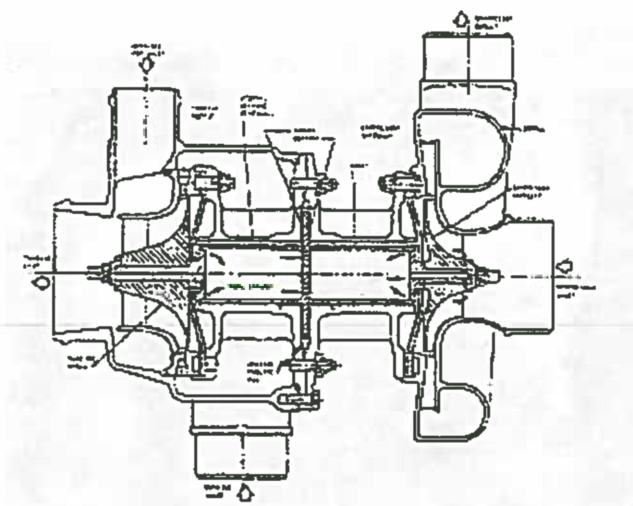

Fig. 14: F-18 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

Cessna-550 - In 1977 AiResearch developed a small two-wheel air cycle machine for commuter aircraft such as the Cessna-550. The machine is shown in Fig. 15. It runs at 105,000 rpm. The same machine is being used for EMB-120, ATR-42 and ATR-72 aircraft with minor modifications.

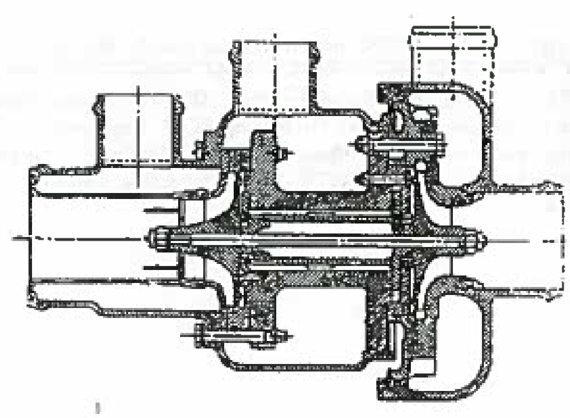

Fig. 15: Cessna-550 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

F-15/F-14 - Following success of the F-18, AiResearch developed a slightly larger two-wheel air cycle machine for F-15 aircraft in 1977. The same machine with slight modifications was used for F-14 aircraft in 1978. Photograph of F-14 machine is shown in Fig. 16.

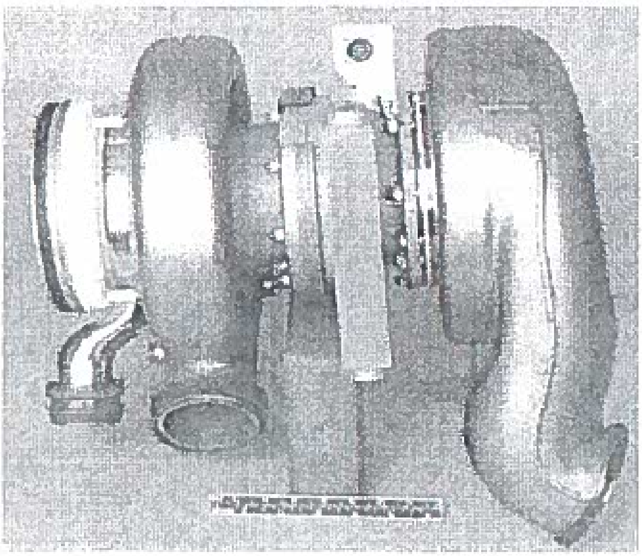

Fig. 16: F-14 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

767/757 - The 767/757 aircraft was launched by Boeing in 1979. Knowing the success of DC-10 ACM, Boeing required that 767/757 ACM must have foil air bearings. This was the first aircraft where the customer required a foil bearing ACM. Cross section of the machine developed by AiResearch is shown in Fig. 17. It is also a three-wheel machine like the DC-10, but the design is much simpler.

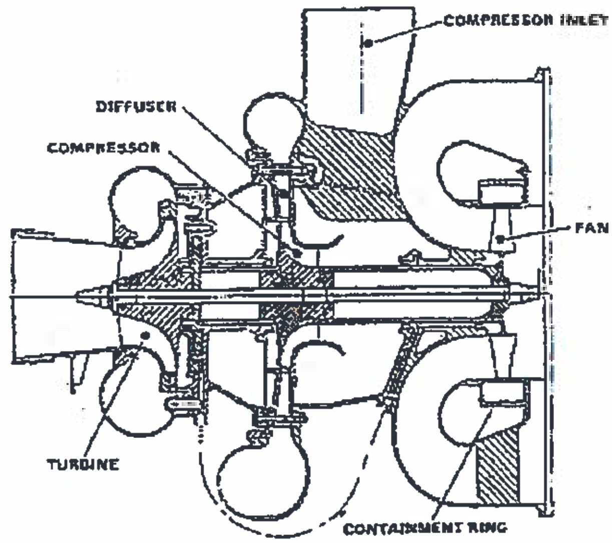

Fig. 17: 767/757 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

F-16 - The F-16 aircraft is built by General Dynamics. Its production was started in 1974. An air cycle machine with a ball bearing design was built by Hamilton Standard. In 1982, due to additional electronics on the aircraft, the Air Force required a new air cycle machine. AiResearch modified the existing F-18 machine and qualified for F-16 aircraft, which is now in production. A photo of the F-16 ACM is shown in Fig. 18.

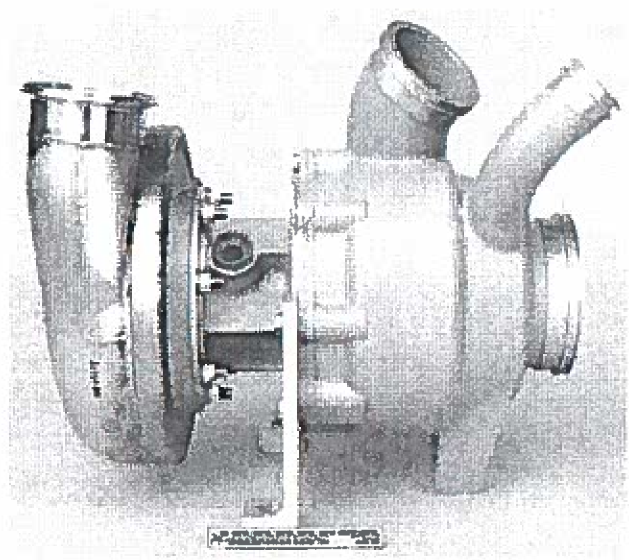

Fig. 18: F-16 Foil Bearing Air Cycle Machine
(Developed by AiResearch)

M1A1 - AiResearch also developed a foil air bearing air cycle machine for the M1A1 tank environmental control system. The machine has a turbine and a fan on a common shaft. The machine worked well during the last Gulf War in spite of heavy sand and dust in the desert. The machine is shown in Fig. 19.

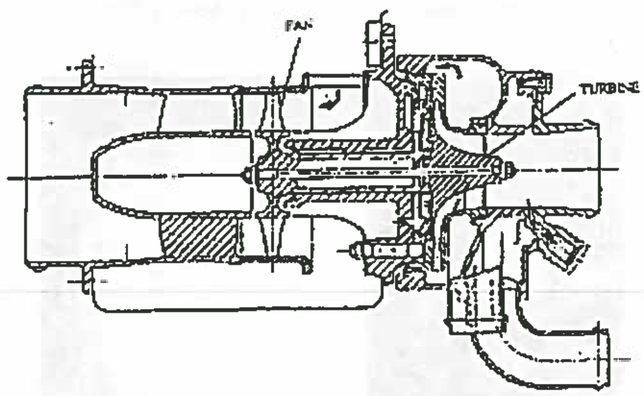

Fig. 19: M1A1 Tank Foil Bearing Air Cycle Machine (Developed by AiResearch)

L-1011 - The L-1011 machine was the first production foil bearing machine produced by Hamilton Standard. As can be seen in Fig. 20, it is a three-wheel machine with fan, compressor and turbine rotors. These ACMs were placed on the last five production L-1011 aircraft and have been performing well. Figure 21 shows an L-1011 flight test unit that was returned for inspection after 13,000 hours of service at Saudia. The unit was in excellent working condition despite being heavily contaminated by sand, cement and oil. This shows the ability of the foil bearings to operate in severe environmental conditions.

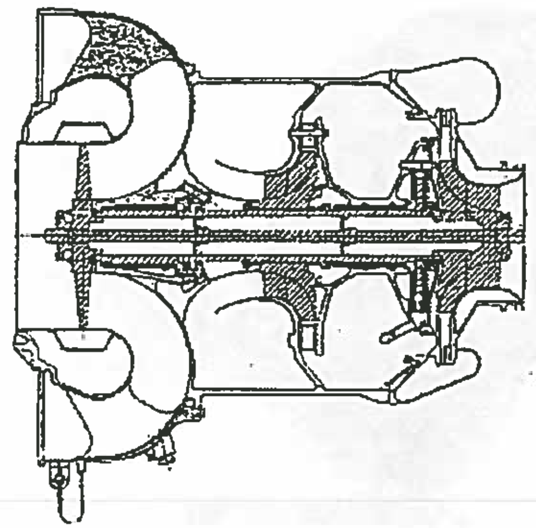

Fig. 20: L-1011 Foil Bearing Air Cycle Machine (Developed by Hamilton Standard)

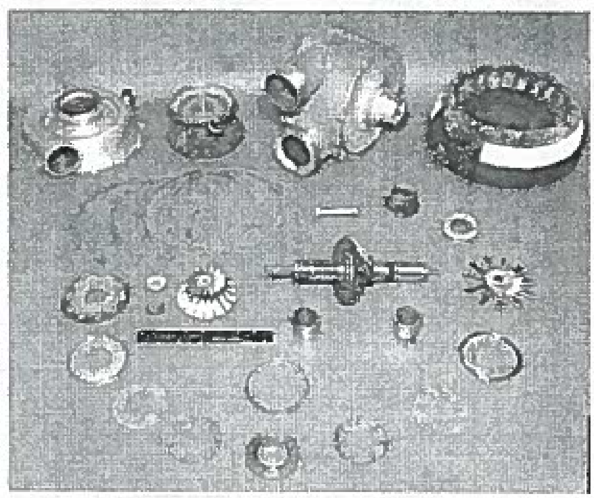

Fig. 21: L-1011 Foil Bearing Air Cycle Machine After 13,000 Hours in Saudia Aircraft

747 - Hamilton Standard supplies the ECS on the 747 aircraft. Aircraft production started in 1970. Air cycle machines on all aircraft built until 1987 are ball bearing units. Under pressure from the airlines, Boeing and Hamilton Standard decided to change the ECS system to incorporate foil air bearing ACMs. All 747 aircraft built since 1988 have foil bearing ACMs. Over 1000 machines are flying successfully. These machines are performing well in the field, and to date, over 12 million flight hours have been accumulated. The machine has shown an MTBF (mean time between failure) of over 100,000 hours in the field. A photograph of the 747 machine is shown in Fig. 22.

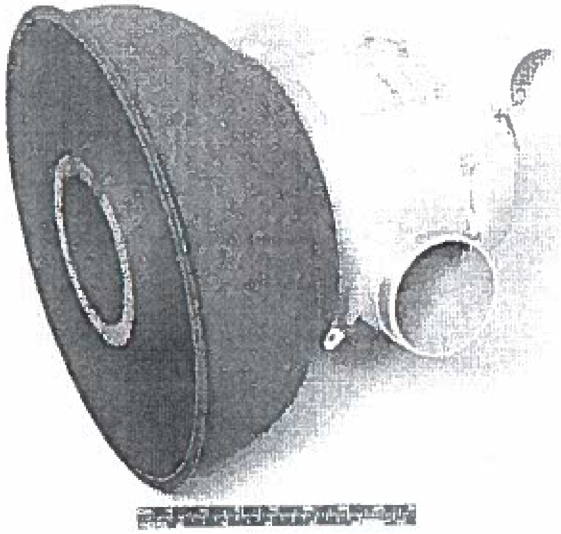

Fig. 22: 747 Foil Bearing Air Cycle Machine (Developed by Hamilton Standard)

B-1B - The foil bearing machine shown in Fig. 23 was developed for use on the B-1B aircraft by Hamilton Standard. The unit runs at 95,000 rpm. To date, this two-wheel foil bearing machine has logged over 120,000 flight hours. One hundred production units and thirty spares were delivered for use on this long range bomber.

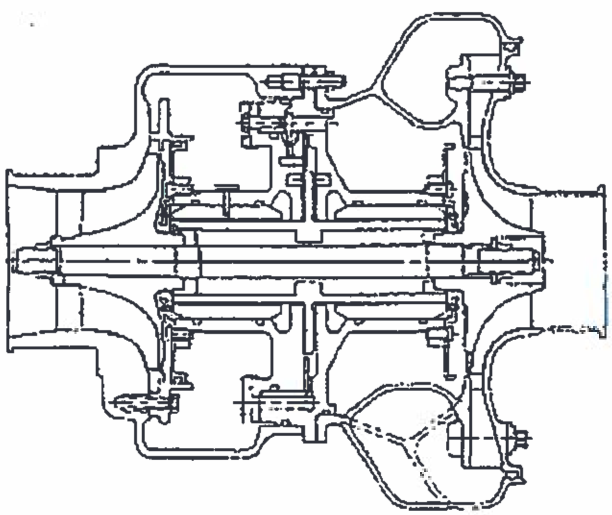

Fig. 23: B-1B Foil Bearing Air Cycle Machine (Developed by Hamilton Standard)

B-2 - Hamilton Standard builds the ECS system on the Air Force B-2 Stealth bomber. The system contains a high speed foil air bearing supported ACM. The B-2 ACM, shown in Fig. 24, completed a rigorous qualification program in 1989. After one test that included 7500 start/stop cycles, the bearings were inspected and found to be in like-new condition. The hardware for this machine is shown in Fig. 25. Another test included 1600 hours of endurance running. These tests show the durability of the foil bearings. Many B-2 aircraft are flying successfully using foil air bearing ACMs.

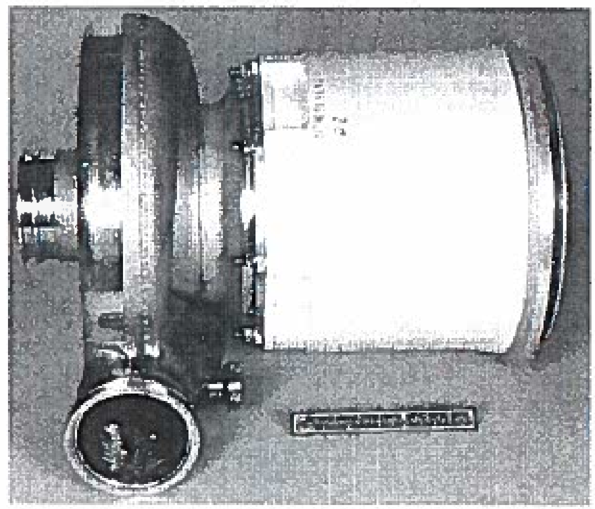

Fig. 24: B-2 Foil Bearing Air Cycle Machine (Developed by Hamilton Standard)

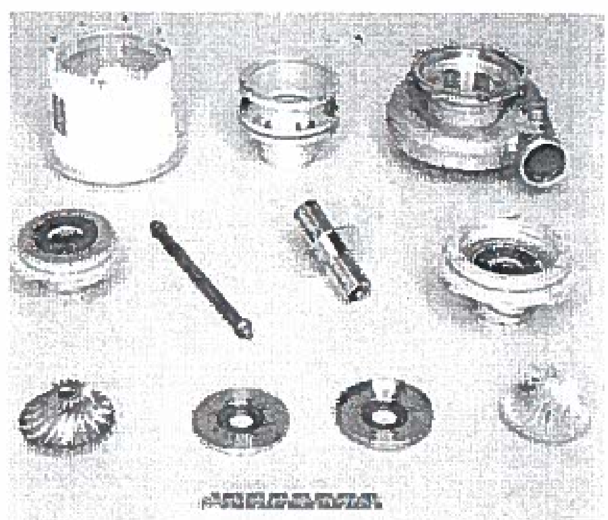

Fig. 25: B-2 Foil Bearing Air Cycle Machine After 7,500 Start-Stops

SAAB-2000 - Hamilton Standard has designed, developed and qualified a midsize foil air bearing ACM for use on SAAB-2000 commuter aircraft. Many aircraft with these units are flying successfully. Shown in Fig. 26, this three-wheel machine will also be used on other large commuter aircraft.

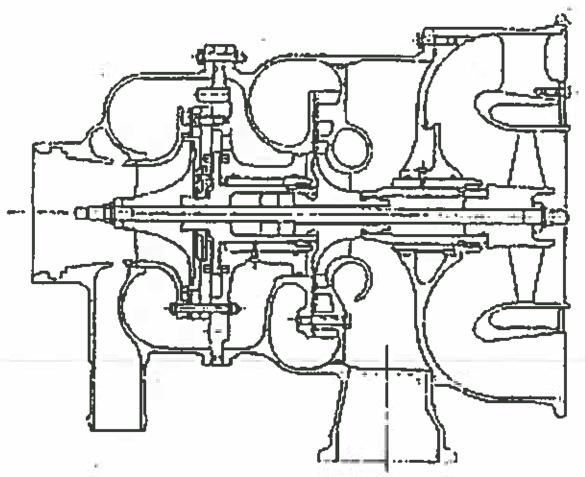

Fig. 26: SAAB-2000 Foil Bearing Air Cycle Machine
(Developed by Hamilton Standard)

777 - Hamilton Standard has developed and qualified an ECS system on the latest Boeing aircraft 777. The system uses the world's first four-wheel air bearing ACM. All of the previous machines are either two-wheel or three-wheel machines. The unit has successfully passed 36,000 start-stop cycles, which is equivalent to 30 years life of the machines. Many 777 aircrfat are flying with production ACMs. Approximately 300 aircraft have already been sold and will be delivered in the near future. A cross section of the ACM is shown in Fig. 27.

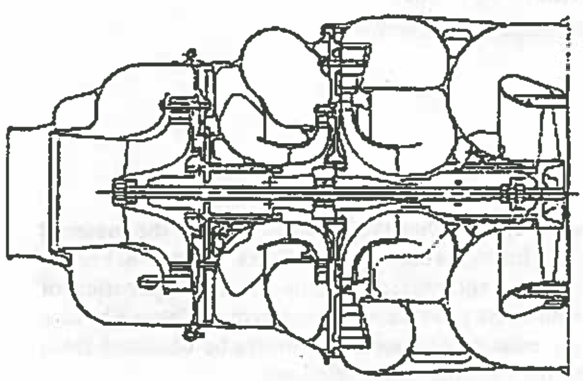

Fig. 27: 777 Foil Bearing Air Cycle Machine
(Developed by Hamilton Standard)

ADDITIONAL APPLICATIONS

Many applications of foil air/gas bearings other than air cycle machines have been built and successfully tested, but nothing appears to be in production at this time. AiResearch successfully tested a vapor cycle machine on Navy P-3 aircraft with Freon as the working fluid. A machine similar to this will be built for F-22 aircraft. A cryogenic foil bearing turbo pump working in liquid oxygen was built by AiResearch and successfully tested by NASA. Both AiResearch and Hamilton Standard have built foil bearing high speed fans for the Space Station. Several cryogenic foil bearing turboexpanders for air separation plants for the Navy have been built. AiResearch built a high temperature foil bearing APU (Auxiliary Power Unit) for B-2 aircraft in 1985. The unit ran successfully, but could not pass the endurance test. It was concluded that coating wear at high temperature was the cause. Since then much research has been done in the areas of foil coating and bearing design. Recently R&D Dynamics jointly with Allison Engine Company built a missile engine with a hot end foil bearing good up to 1000°F.

CONCLUSIONS

Foil bearings have been extremely successful for air cycle machines. They have increased the reliability of these machines up to tenfold. Even though several machines have been built for other applications, the work has not been pursued by the same vigor and commitment for various reasons. Foil bearings have strong potential for the following applications:

A. A small general aviation gas turbine engine supported on foil bearings will be more reliable and cost less than existing engines.

B. Oil free cryogenic turboexpanders supported on foil bearings will be more reliable and increase efficiency of gas separation plants.

C. Highly reliable and less expensive APU's can be built for various aerospace and ground vehicles using foil bearings.

D. Recent concept of foil bearings provide potential for low cost bearings using automated manufacturing methods for commercial applications; e.g. automobile gas turbine engines, vapor cycle centrifugal compressors and commercial air/gas compressors.

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The materials presented here have been compiled from various sources including those from airlines and military customers. Some cross sections and photos were reproduced or redrawn from previously published material or sales brochures. Some photos were retaken from hardware available with various customers.

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Volume Editor

Prof. Martin Hocking
Department of Chemistry
University of Victoria
P.O. Box 3065, STN CSC
V8W 3V6 Victoria, BC, Canada
hockingm@uvic.ca

Assistant Editor

Diana Hocking
Department of Geography/CCA
University of Victoria
P.O. Box 3050, STN CSC
V8W 3P5 Victoria, BC, Canada

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1 cu ft of air is ≅ .08 LBM @ STD. CONDITIONS

environmental control systems must operate under extreme environmental conditions, unlike those for buildings. Compressed air used for cabin pressurization is also used for ventilation, though it must be emphasized that pressurization and ventilation serve two distinct purposes. The primary purpose of pressurization is to maintain the P_{O_2} at acceptable levels while ventilation is a way of eliminating air pollutants from aircraft [51]. Environmental systems must also prevent rapid changes in cabin pressure, which can cause sudden changes in the volume occupied by gases in the body cavities and result in discomfort.

Flow rate has almost no impact on P_{O_2}; the occupants consume only a small portion of the oxygen in the air and, according to the NAS report, ventilation rates well below those normally present in aircraft would not seriously affect P_{O_2} [13]. FAR 25 minimal designs outside air flow rate of 0.25 kg/min (0.55 lb/min) per cabin occupant implies that oxygen is supplied into the cabin at 0.058 kg/min (0.127 lb/min) per person. Assuming a typical sedentary adult consumes oxygen at about 0.44 g/min [46]; occupants' oxygen consumption reduces the P_{O_2} levels by about 0.8% compared with a P_{O_2} reduction of up to 25% to the reduced cabin pressure. Thus, these conditions provide an adequate oxygen concentration within the cabin even at lower flow rates, as long as the cabin is adequately pressurized [51]. 10a

Four factors are considered in determining the flow rate requirements: (a) outside air necessary to remove contaminants; (b) conditioned air to remove heat from the cabin; (c) total flow rate to provide adequate ventilation; (d) outside air required to provide oxygen and to pressurize the aircraft. In older aircraft only outside air was supplied to the cabins. Under these conditions the outdoor air flow necessary to comply with all four requirements called for larger air flow rates than specified in FAR 25. For example, the flow rate specified to maintain temperature control could be more than twice the FAR specified for outside air for contaminant control.

This fact led to the practice of air recirculation to achieve higher rates of total airflow independent of outdoor air flow rates. This way the cabin can benefit from good circulation and conditioned air without causing cold drafts. The temperature of the air to be provided can be determined using the steady state heat balance as follows:

$$T_c = T_s + (Q/m_s)(1/c_p) \tag{3}$$

Where

T_c Temperature in the cabin, °C

T_s Temperature of the air supplied to the cabin, °C

Q Amount of heat that must be added or removed from the cabin.

m_s Flow rate of conditioned air supplied to the cabin, kg/s
c_p Specific heat of the air, 1000 J/kg °C

Naturally, this implies that filtration is necessary. In new aircraft this is conducted using high efficiency particulate filters (HEPA), with minimal efficiency of 99.7% for 0.3 μm particles. These filters, while effective in removing particles from the recirculated air, including bacteria and viruses, need to be used in combination with activated charcoal or similar filters if chemical absorption of gaseous contaminants is to be accomplished. While it is understood that recirculation is not a substitute for outside air, outdoor air flow rates in older aircraft without recirculation range from 5.9 to 9.6 L/s (12.4–20.4 cfm) while on aircraft with recirculation range from 3.6 to 7.4 L/s (7.6–15.6 cfm). These values reflect the responses of Airbus and Boeing to NAS in 2001 [13]. 10b

An outside air change rate of 10–15 air changes per hour and a total air change rate of 20–30 air changes per hour are normally adequate to maintain cabin pressure and a comfortable thermal environment at cruise altitude. Mass flow is the unit used in the FAR to specify the ventilation requirements. In fact the mass flow rate is more important that the volume flow rate. Liters per second (L/s) or cubic feet per minute (cfm) are common units to express flow rates, but this practice can lead to ambiguity if pressure and temperature are not stated at the same time. 10c

For example, 1 m³ (35 ft³) of air at sea level will expand to 3 m³ (106 ft³) at cruise altitude pressure and temperature. Considering the FAR 25 minimum ventilation requirement of 0.25 kg/min (0.55 lb/min), at sea level and atmospheric temperature of 15 °C, this corresponds to a volumetric flow rate of 3.4 L/s, which, at the maximal allowed cabin pressure altitude of 2440 m (8000 ft), and a typical cabin temperature of 22 °C (72 °F), is 4.7 L/s (9.9 cfm). At the ambient outside atmospheric pressure at an altitude of 12 000 m (39 300 ft) and an atmospheric temperature of −63 °C (−81 °F) the volumetric flow rate would be 13.0 L/s (27.6 cfm).

Contaminants may be generated inside the cabin or outside the cabin or may form from chemical reactions occurring inside the cabin. Source emission fluctuations and ventilation rates influence the concentration rates of contaminants within the cabin. Generation of contaminants within the cabin can be assessed using the basic steady state ventilation equations. For a particular contaminant "i" maybe expressed as [47]:

$$D_{c,i} = D_{o,i} + S_i/V_o \tag{4}$$

and climb is a .98. And that's -- that's MG/M cubed. What does MG/M cubed?

A Okay. Let's first make sure I'm reading the same thing you're reading first. I got on the table here that says takeoff and climb. Sample ID, 01-A, the nitrogen dioxide. Is that the one you're look at?

113 Q Yes.

A Okay. And you got oil mist .90 -- 98. Apparently it's below that particular concentration of detection. So the system is such that he cannot detect anything below .98 milligrams per metre cubed in the air.

114 Q Okay. And --

A And he compares that to the Osha PEL exposure level of five milligrams per metre cubed. And the ACGIH TLV of five milligrams per metre cubed.

115 Q Okay. Tell us what is the Osha PEL? Explain that to us.

A Personal exposure limit. It's usually -- and I have to check this out. It's usually based on an eight-hour exposure, which is supposed to protect not all but most of workers under proper healthy conditions during an exposure during when -- you are exposed to that particular level in the air.

So technically the worker can be exposed to less than five milligrams per metre cubed for an eight-hour period without experiencing any nasty consequences.

116 Q And typically that's going to be something closer to sea level? In a factory? Or --

A That is all based on sea level material. That's right.

117 Q Okay. And what does it mean -- what's the difference in the human body between a standard -- a sea level standard and a cabin attitude of 8,000 feet?

A Well, depending on where you're used to living. If you are used to living at sea level, you go to altitude and the aircraft is pressurized similar to the same air pressure you would find around 8,000 feet of altitude. So you have a hypoxic condition and a lack of oxygen. So this is another stressor that a person is exposed to. So you have to be very careful not to translate what is acceptable at ground level, sea level, to a situation where all kinds of other stressors are operating, such as a lack of oxygen. And in this case, also the type of work that pilots do, which is -- doesn't give you a great variability with

what you can get away with. So they need to identify specific environments if you want to apply those PEL levels to different situations, because of course they might not always be accurate under those conditions.
118 Q So is it your opinion that the Osha PEL even for oiliness would be -- would not be applicable to a cabin environment at an altitude of 8,000 feet?
A It certainly -- well, we know -- and since the body gets stressed under those conditions, you would expect that level to have a proper PEL for oil mist from Osha should be lower than that in the air.
119 Q But we don't know what that would be?
A Precisely.
120 Q There's no such standard, is there?
A That's correct. Now, I have real problems with saying oil mist. What type of oil mist are we talking about? Mineral oil is one thing, but when you start reading the literature, there are many different types of oil mists. And the ingredient of the oil mist are the important ones. So oil mist is sort of a material that is sort of inert. It doesn't really have any pharmacological affect on the body. But it sort of coats the inside of

your lungs preventing oxygen from getting into the blood stream. But now you have an oil material that has neurotoxins in it. So this does not apply to any other oils that I'm aware of that are important. Even automobile oils are different from that objective.

121 Q So just to make sure that that's clear. The environmental -- I'm sorry. This industrial hygiene assessment, although they tested for oil, they did not test for jet-engine oil -- or I'm sorry. BP 2380 oil and its elements or constituents?

A No, they just basically take a filter, I presume -- and that's a standard procedure -- and they pull air through it with a pumping system. And then they measure the filter and say it's so many milligrams of oil were found on the filter.

122 Q Do you have -- do you think that it's -- I guess I'm going to call it a lack of due care, to do an industrial hygiene assessment that doesn't test for the kind of contaminants that would be expected?

A Well, that's correct. There are two possible reasons for that, and I don't want to be difficult here. But either the person is not aware of the

Q. And are you currently employed with anyone?
A. No.
Q. Who was the last employer that you worked with?
A. Northrop Grumman.
Q. And how long did you work with Northrop Grumman?
A. I believe about three, four years, approximately.
Q. And were you employed with Northrop Grumman in May of 2011?
A. Yes.
Q. Mr. Davidson has filed with the Louisiana workers' compensation office a claim asserting injuries that resulted from a flight that occurred in May of 2011. And one of the reasons that we're here today is to get information about that flight.
I'm told that you were the pilot of the flight where an incident occurred involving fumes. Is that correct?
A. Yes, sir.
Q. And was the date that this incident occurred May 31st, 2011?
A. Yes, sir.
Q. In your own words, could you describe for us what happened on that date?
A. Well, we made the flight. Of course, prior to that flight, a different pilot had flown the plane and complained of the fumes and smoke and said, "The airplane

needs to be fixed, shouldn't be flown anymore," and he basically said he wasn't going to fly it anymore. So --

Q. Was that Bill O'Connor?

A. Yes, sir.

And so Ken Davidson and myself were asked to go fly a flight a few days later to verify those smoke and fumes which they knew the airplane was making. We really didn't want to do it, but, you know, it's your -- when it's your job, you -- most of the time an employer, especially our managers, pressed the issue pretty -- pretty hard to go ahead and fly the plane.

And about -- well, as soon as you get in the plane, you smell the smoke and fumes, but we went ahead and flew -- flew the mission or attempted to. And about -- oh, right after takeoff, you know, the fumes were there. The smoke came later. 12b 12a

But during -- during that one-hour flight or, you know, a little over an hour, after we got up to altitude and -- I think 28,000 feet, the -- the smoke and fumes were so bad that burning eyes, coughing, and more difficulty breathing.

I asked Ken how he was feeling, and of course, he was -- appeared to me to be about, you know, halfway intoxicated. And I -- I told him, I said, "I don't feel competent with the safety of the flight anymore," and we

were going to abort the flight.

I contacted ATC. We got an immediate descent. Because at that altitude, the smoke and fumes are a lot stronger than they are at a lower altitude. So we got the airplane down as soon as we could, depressurized the cabin, tried to clear the smoke. I used oxygen as much as I could, because I was kind of concerned about how -- how safe I would be and if we could even make it to the airport.

But we did find our way back to the airport, landed. And to be honest with you, I -- neither one of us, Ken or myself, can remember how we got back to the hotel from the airport.

And we reported that incident to our supervisors back at Northrop Grumman in Peachtree City. And they -- the best I can remember, they was kind of disgusted, you know, because they really expected us to continue flying the plane and discredit the previous pilot's report.

And from then on, we were kind of treated like traitors to the company.

But Ken, I know, was at that time -- I can't think of the word to describe it, but he was kind of out of it, and I think both of us were pretty well overwhelmed by the fumes.

Q. Where did that flight that you and Mr. Davidson have

originate?

A. In Schenectady, just out of Albany, New York.

Q. That's in -- that's in New York; correct?

A. Yes, sir.

Q. And do you have the identifiers for that particular plane that you were flying?

A. It's November 690 echo hotel.

Q. And what kind of plane was it?

A. That's a -- designated an AC-90. It's a Turbo Commander.

Q. And do you know the manufacturer?

A. Originally Rockwell Commander, and I think they've been in and out of the manufacturing business, and I think Air Research -- I'm not sure who's responsible for the airframe at this point.

Q. Where were you and Mr. Davidson relative to one another while the flight was going? I, obviously, presume that you're in the pilot seat. Where was Mr. Davidson located?

A. He's about three-quarters of the way back in the cabin to the rear.

Q. And is there any divider or separator or door that separates where you were from from Mr. Davidson?

A. No. It's -- it's an open cabin and cockpit configuration. And actually, Mr. Davidson sits in the

area where the -- those smoke and fumes first enter the cabin.

Q. And approximately in feet how far away would he have been from where you were flying the airplane?

A. Oh, 10 -- 10 feet maybe.

Q. Do you at this time know what the source of the fumes were?

A. Well, they're -- there's only one source of air to come into the cabin, and that's through the -- excuse me -- the bleed air system. The -- the airplane is pressurized, heat and air, off from bleed air from the engines. It goes through what's called an air cycle machine where -- with an evaporator and condensers and turned into pressurized air and, of course, heating and cooling. And there is no -- there is no other air source.

Q. Do you know what was causing the fumes on that flight?

A. Yeah. It -- I'd been flying that airplane for almost three years previous to that, and we constantly complained about the smoke and the fumes.

It's -- it's a common problem with those airplanes and most all airplanes that use the TPE331 engines. The -- if there's any -- any kind of oil leakage around the engine seals or around the engine inlet, that oil is introduced directly into the bleed air.

12c

Of course, after high temperature and pressure and -- breaks down -- that oil back down into organophosphates, tricresyl phosphates, which are highly toxic. And that air goes into the air cycle machine, which if it's malfunctioning, further contaminates the air with fumes and smoke.

And in that airplane's condition it was in at the time will overheat the ductwork and further irritate the situation with basically the cooked materials in that ductwork, which even adds a whole new array of -- of chemicals and by-products of being overheated.

When you're at the higher altitude where it can be, you know, minus 20 degrees would require more heat and more air for the pressurization. And at some point, that system in that aircraft will use direct bleed air into the cabin without going through the air cycle machine to augment the cabin pressurization and heat.

And for a long time, which we complained about and it never was fixed, the temperature control would go full hot and basically just, like I said, cook the ductwork and overheat everything, and that's where you get the smoke, also.

So that pretty much, I think, summarizes the -- the source. And there is no other source for heat, air, smoke, and the fumes.

Q. How long do you estimate that you and Mr. Davidson were exposed to these fumes on that flight of May 31st, 2011?

A. From the time we got in the cabin. I mean those -- that -- those materials are kind of impregnated in the interior of the aircraft from previous flights, so from the time we got in the cabin till -- till we landed, which was I think -- I'd have to look at the logbooks, but I think it was over an hour, probably an hour and a half, a good hour and a half of exposure.

Q. You mentioned that people knew about this problem. Who was it that knew about this particular problem before this flight that you -- that you know of firsthand?

A. Our managers. Dennis Monday; probably the fleet manager; the chief pilot, Matt Boone; the ops manager, Dan Burke; and most all the pilots and operators in the company knew of the smoke and fumes that were involved with that airplane.

Some of them just got to the point they refused to fly in it because of the -- but it -- but everybody in the maintenance department was aware of the airplane. And then in our management, they were -- they were informed almost daily, practically every flight about the -- you know, the fumes and the smoke that I would complain about as well as the other pilots, also.

Substance	Name it is listed by in Table 1
Tin compounds, inorganic, except SnH_4, (as Sn)	Tin compounds, inorganic, except SnH_4, (as Sn)
Tin compounds, organic, except Cyhexatin (ISO), (as Sn)	Tin compounds, organic, except Cyhexatin (ISO), (as Sn)
Titanium dioxide	Titanium dioxide
TMA	Trimellitic anhydride
TNT	2,4,6-Trinitrotoluene
Toluol	Toluene
Tolyl chloride	Benzyl chloride
Tosyl chloride	*p*-Toluenesulphonyl chloride
Toxilic anhydride	Maleic anhydride
Triatomic oxygen	Ozone
Trichloroethene	Trichloroethylene
Trichloromethane	Chloroform
Triiodomethane	Iodoform
Trike	Trichloroethylene
Trilene	Trichloroethylene
Trimethylbenzenes, all isomers or mixtures	Trimethylbenzenes, all isomers or mixtures
Tri-*o*-cresyl phosphate	Tri-*o*-tolyl phosphate
Triphenyl phosphate	Triphenyl phosphate
Tripoli, respirable dust	Silica, respirable crystalline
Trydimite, respirable dust	Silica, respirable crystalline
Tungsten and compounds (as W)	Tungsten and compounds (as W)
Turpentine	Turpentine
VCM	Vinyl chloride
Vinyl carbinol	Allyl alcohol
Vinyl chloride monomer	Vinyl chloride
Vinyl cyanide	Acrylonitrile
Vinylbenzene	Styrene
water-soluble nickel compounds	water-soluble nickel compounds
Wool process dust	Wool process dust
Xylol	Xylene, *o*-,*m*-,*p*- or mixed isomers
Yttrium	Yttrium
Zinc chloride, fume	Zinc chloride, fume
Zinc distearate	Zinc distearate
Zinc distearate	Zirconium compounds (as Zr)
α-Chlorotoluene	Benzyl chloride

Substance	CAS Number	Workplace exposure limit				Comments
		Long-term exposure limit (8-hr TWA reference period		Short-term exposure limit (15 minute reference period)		The Carc, Sen and Sk notations are not exhaustive. Notations have been applied to substances identified in IOELV Directives
		ppm	$mg.m^{-3}$	ppm	$mg.m^{-3}$	
Trimellitic anhydride	552-30-7	-	0.04	-	0.12	Sen
Trimethylbenzenes, all isomers or mixtures	25551-13-7	25	125	-	-	
3,5,5-trimethylcyclohex-2-enone	78-59-1	-	-	5	29	
Trimethyl phosphite	121-45-9	2	10	-	-	
2,4,6-Trinitrotoluene	118-96-7	-	0.5	-	-	Sk
Tri-*o*-tolyl phosphate	78-30-8	-	0.1	-	0.3	
Triphenyl phosphate	115-86-6	-	3	-	6	
Tungsten and compounds (as W) soluble compounds insoluble compounds and others	7440-33-7	 - -	 1 5	 - -	 3 10	
Turpentine	8006-64-2	100	566	150	850	
Vanadium pentoxide	1314-62-1	-	0.05	-	-	
Vinyl acetate	108-05-4	5	17.6	10	35.2	
Vinyl chloride	75-01-4	3	7.8	-	-	Carc
Vinylidene chloride	75-35-4	10	40	-	-	
Wool process dust	See para 43	-	10	-	-	
Xylene, *o*-,*m*-,*p*- or mixed isomers	1330-20-7	50	220	100	441	Sk, BMGV
Yttrium	7440-65-5	-	1	-	3	
Zinc chloride, fume	7646-85-7	-	1	-	2	
Zinc distearate inhalable dust respirable dust	557-05-1	 - -	 10 4	 - -	 20 -	
Zirconium compounds (as Zr)		-	5	-	10	

REPORT

of the

MAY 31, 2011 COMMANDER 690A CABIN AIR FUME INCIDENT

By:

Matthew D. Lykins AP, IA

March 4, 2016

RFI File No. 16FE0059

EXHIBIT 2

Robson Forensic

Engineers, Architects, Scientists & Fire Investigators

MAY 31, 2011 COMMANDER 690A
CABIN AIR FUME INCIDENT

REPORT **March 4, 2016**

1.0 INTRODUCTION

On May 31, 2011, Thomas Farmer was performing his duties as pilot in command of a Turbo Commander model 690A aircraft registered as N690EH. Kenneth Davidson was also on board the aircraft performing his duties as a remote sensing equipment operator. The purpose of the flight was to collect data via the onboard sensing equipment pursuant to a contract held by Northrop Grumman. It was reported that while flying at a cruise altitude of 28,000 feet they experienced a cabin air toxic fume event. At the time of the event, the aircraft was fitted with a Fairchild air cycle machine as part of the cabin environmental control system.

Robson Forensic Inc. was retained to investigate this matter. The purpose of my investigation was to determine if the Fairchild air cycle machine was defective in a manner that caused the toxic fume event.

Robson Forensic, Inc. invoices the work associated with this investigation at a rate of $375.00 per hour. I have included a CV outlining my qualifications with this report as well as a history of my testimony.

I may use the following materials as exhibits to illustrate testimony: All items referenced in section 2.0 Available Information below and all citations and footnoted items in this report.

2.0 AVAILABLE INFORMATION

2.1	05/30/2014	Original Complaint
2.2	01/14/2016	Expert Report of Don Hansen, M.E., P.E.
2.3	12/03/1984	Gulfstream Commander 690A/B Maintenance Manual P/N M690002-2
2.4	07/22/1994	Gulfstream Commander 690A/B Illustrated Parts Catalog P/N M690002-4
2.5		Bates # TC 00161 - 00163, 00299 - 00362
2.6		Bates # NG 0001 - 0052, 0136, 0146, 1062 - 0164

2.7		Bates # Northrop 000019 - 000021, 000046 – 000056, 000060 – 000061, 000063 – 000065, 000067 – 000073, 000075, 000169 – 000170, 000176 – 000178, 000269 – 000287, 000421 – 000422, 000503 – 000506, 000508, 000514 – 000517, 000653 – 000658, 000778, 000783, 000784, 000786 – 000788, 000801 - 000803, 000817 – 000819, 000885, 000886, 000905, 000906, 000919 – 000921, 000966 – 000970, 000986 – 000989, --1169 – 001420.
2.8		Bates # FAIRCHILD 00000001 – 00000026, 00000039 – 00000065.
2.9		Bates # EC000037 – 000051, 000053 – 000108, 000147 – 000255, 000266, 000267, 000317 – 000336, 000362 – 000364, 000385, 000386, 000450 – 000455, 000462 – 000464, 000474 - 000483, 000535 – 000537, 000601 – 000603, 000615 – 000617, 000655 – 000656.
2.10		Bates # CD 00001 – 00011, 00013, 00018 – 00020, 00028 – 00033, 00035, 00036, 00047 – 00054, 00062, 00096, 00099, 00100, 00104, 00107, 00108, 00318 – 00332.
2.11	09/05/2012	Deposition transcript of John Probst with exhibits 1 – 9.
2.12	11/30/2012	Expert report of Richard C. Pleus, PhD., Bates # PLAINTIFF 002822 – 002864.
2.13	12/13/2012	Pleus rebuttal report of Harrison & Van Netten, Bates # PLAINTIFF 002789 – 002821.
2.14	02/12/2016	Declaration of Paul Dziorny

3.0 BACKGROUND

The incident Turbo Commander aircraft is a twin engine turboprop aircraft model 690A, serial number 11309 and manufactured by Rockwell International in 1975 (Aircraft). It is registered with the Federal Aviation Administration as N690EH and was owned, operated and maintained by Northrop Grumman Corporation at the time of the fume event. The Aircraft has a history of reported in-flight cabin smoke / fume events before and after the May 31, 2011 event. Furthermore, as of the date of this report, no evidence has been presented to the author confirming these events have been remediated and the associated root cause identified.

The aircraft cabin is pressurized for high altitude flight operations using engine bleed air taken from the compressor section of each engine and routed through the cabin environmental control system (ECS) and then into the aircraft cabin. The purpose of the ECS is to receive the high pressure / high temperature engine bleed air supply and condition its pressure and temperature and then deliver the conditioned air to the aircraft cabin during all phases of flight. Figure 1 depicts a schematic of the Aircraft's

ECS (red markups added).[1] The Aircraft's ECS conditions the temperature of the air by routing a portion of the engine bleed air through a refrigeration unit comprising of two air-to-air heat exchangers and the Fairchild air cycle machine (ACM). The cool air is then introduced into a cabin air plenum where it mixes with compressed hot engine bleed air that bypassed the heat exchangers and ACM. The hot air valve regulates the amount of hot air introduced into the plenum as demanded by the pilot's heater control. The cabin pressurization is controlled by regulating the amount of air that exits the cabin through outflow valves, which are separate from the ECS.

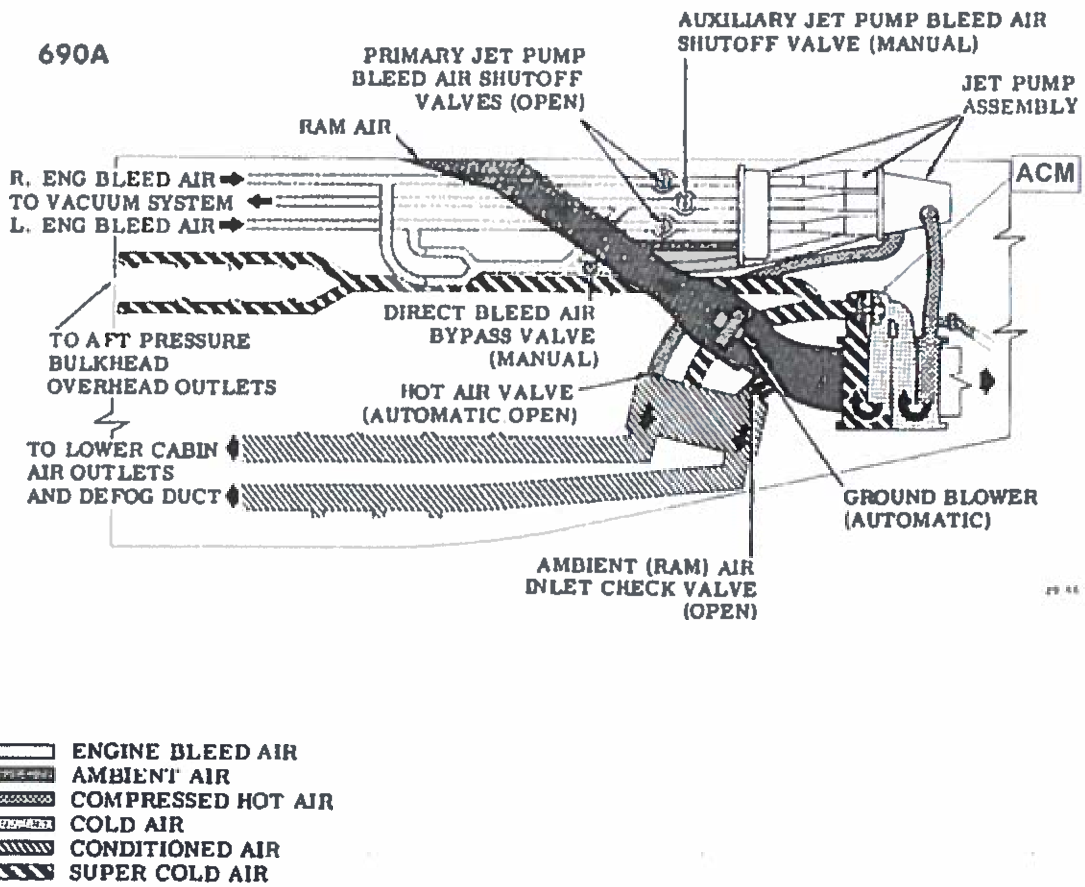

Figure 1

The incident air cycle machine is a Fairchild model BUR-20-1D and part number 977018-1 and was designed and manufactured by Fairchild Controls Corporation (Fairchild). Fairchild manufactured and sold ACMs for various aircraft applications including the Turbo Commander 690A between approximately 1950 and 1980. Figure 2 is a photograph representation of the Fairchild model BUR-20 ACM.[2] Since there are

[1] Gulfstream Commander 690A/690B Maintenance Manual revised Dec 3, 1984, section IX, Figure 9-9, p. 9-18.

[2] Declaration of Paul Dziorny, Fairchild Vice President, Chief Engineer, paragraph 10.

still Fairchild ACMs in service today, the company continues repair and overhaul support through a FAA Parts Manufacturer Approval (PMA) issued to Fairchild on March 14, 2000.[3] The ACM is the only component of the Aircraft's ECS that was manufactured by Fairchild.

Figure 2

The operating principle of an air cycle machine is that air cools as it performs work. The high pressure discharge air from the ACM compressor is used to drive a turbine within the ACM. As a result of the air performing this work, its temperature decreases and is routed away from the ACM to eventually enter the cabin. The turbine is connected to and drives the ACM compressor.

The main components of the ACM are the compressor section which houses the compressor rotor, the turbine section which houses the turbine rotor, the bearing cartridge which contains two angular contact ball bearings and the oil compartment which contains a lubricating wick and 1.25 fluid ounces (about 2.5 tablespoons) of oil. The two bearings support a rotating shaft upon which the compressor rotor is mounted on one end and the turbine rotor on the other end.

The two bearings are fed the required thin film of lubricating oil by means of the oil-laden wick which draws oil from the bottom of the oil compartment at one end and delivers it to the rotating shaft that it makes contact with on the other end. The rotating shaft picks up the oil from the wick and delivers it to the bearings via centrifugal force.

[3] Declaration of Paul Dziorny, Fairchild Vice President, Chief Engineer, paragraph 6.

The rotating assembly within the ACM spins at approximately 36,000 RPM during operation.

The ACM unit is serviced with turbine engine oil (BP 2380) through the oil fill port tube. Overflow of the fill port tube occurs when the ACM is serviced with any more than the specified 1.25 fluid ounces of oil, eliminating the possibility of over-servicing and providing a visual means of determining oil quantity within the oil compartment.

4.0 DESCRIPTION OF THE INCIDENT

On May 31, 2011 Northrop Grumman Corporation pilot, Thomas Farmer (Farmer), and sensor operator, Kenneth Davidson (Davidson), experienced a cabin air fume event while flying the Aircraft at 28,000 feet near Schenectady, NY. Farmer reports:

> Takeoff time is 0810 local, from Schenectady, NY, and we should be on line in about 25 minutes.
>
> At 0840, leveled off at 26,000 ft and on line. Feel my lungs burning, headache, little dizzy, hard to concentrate and think straight. Little disoriented, eyes feel film over them, smell is oily and strong fuel smell. At 0905 local breathing intermittent oxygen from emergency mask to clear head, not getting better with oxygen. Not safe......don't feel competent as Pilot in Command, am calling off flight, return to Schenectady after 1 hour flight, starting descent for SCH airport, to get out of pressurized air in cabin. Headache, disoriented Oxygen not much help. Leveling off at 8000 ft and on ram air, pressurization is off, lungs still not clear, need to cough from irritation, time is 0930 local, 8000 ft altitude, 60 miles out returning to Schenectady airport. Landing is uneventful. Sensor operator, Ken Davidson, and I return to the hotel in town, where we shower off the smell and oily film, but contamination is probably in eyes, respiratory system, and skin. We are both sick, and stay sick for 2 days.[4]

5.0 ANALYSIS AND DISCUSSION

Throughout my career I have owned, operated, consulted, and worked for aviation companies that provided specialized aircraft maintenance services including inspecting, troubleshooting, repairing, modifying and servicing turboprop aircraft. I have developed training courses which covered technical, operational, and safety policies

[4] Written statement Bates stamped DAVIDSON V. ROCKWELL – Northrop 000508.

and procedures for aircraft technicians. As a FAA certificated aircraft technician with Airframe and Power-plant ratings with Inspection Authorization, I have performed analysis and troubleshooting on a wide variety of aircraft systems on aircraft ranging from small single-engine piston aircraft to multi-engine turbine aircraft and rotorcraft. I own and operate a FAA certificated part 145 avionics repair station performing avionics tests and inspections of aircraft across the United States. As an accredited International Business Aviation Council (IBAC) auditor for ARGUS PROS, I audit business aviation operators worldwide to various industry safety standards and best-practices including Safety Management Systems (SMS). I continue to consult aircraft operators and provide technical analysis and troubleshooting of elusive and challenging aircraft technical issues.

Cabin smoke and fume events in pressurized aircraft are well known in the industry and can have one or more of a wide variety of sources including overheated electrical system components, faulty cabin heating/cooling system components, contaminated engine bleed air and/or faulty cabin air filtration system components. Because of this, tracking down and confirming their root cause or causes has the reputation of being a challenging and time consuming process that requires the troubleshooter to have a thorough knowledge of the aircraft and its systems. This must be coupled with a systematic process to evaluate each possible source until the root cause or causes are identified, remediated and then confirmed by testing.

The pilot report from Farmer indicated he was exposed to an "oily film". The two engines and the ACM are he only sources of oil exposed to the ECS on the Aircraft. Because the bleed air for the ECS is taken from the engines' compressor area, an oil leak within or upstream of the compressor could contaminate the cabin air supply.

In order for the Fairchild ACM to be the cause of the cabin air fume event, it would have had to leak oil into the stream of air flowing into the Aircraft cabin. Post-incident investigations of the ACM by Northrop Grumman maintenance manager, John Probst, (Probst) resulted in findings that did not point to the ACM as the cause of the cabin air fume event. The maintenance log entry dated June 24, 2011 reads in part:

> Troubleshoot strong odor in the cabin air system especially during high altitude flight with heat on high and max flow selected. Inspected all the duct work from the engines and found no trace of oil or residue.
>
> Inspected the ACM oil level and found that it was at the same level as it had been 50 flight hours prior to this work. Removed the duct work from the mixing plenum to the ACM, ACM to cabin air plenum, cabin air plenum to the lower fwd cabin air distribution – no abnormalities were noted.

> Removed the ACM. Tested function and rotor drag test on the bench. Found the unit needed 1 ½ inch pounds of torque to rotate. Engineer contacted at Fairchild (ACM Manufacturer) stated that any reading under 10 pounds was sufficient. Further inspected the unit and found no discrepancies – reinstalled in the aircraft.[5]

Probst further clarifies that the ACM oil level staying the same is an indication that the ACM was not leaking:

[Probst 26:13-26:19] Q. If – the fact that it was at the same level it had been at 55 hours earlier, does that indicate that you've got no leakage in the ACM coil"

A. No. That would be a good indication that the – that the system is tight, yes. No oil leak.

Continuing, the same logbook entry indicates that the inspection did reveal faults with the cabin heating components of the ECS:

> Investigated why the cabin cooling system was not functioning – discovered that the hot air valve was remaining in full open position when temp controller system was in auto mode. Valve was controllable in manual mode. Replaced temp controller HYLZ50340 with an overhauled controller s/n 644. Also found upper and lower air inlet duct sensors were out of calibration – readjusted both sensors to the limits specified in the Commander AMM.

Post-maintenance operational tests did not reproduce cabin air smoke or fumes and the aircraft was returned to service. Yet less that 35 flight hours later, pilots reported again of cabin air smoke and fumes. The logbook entry dated August 1, 2011 reads in part:

> Ground ran the aircraft to verify the oily odor and reported smoke in the aircraft. Verified that there is, under certain conditions when max heat is selected, smoke that can be seen and a strong oily odor is apparent.

Probst expands that the ground run tests revealed that with the heat control turned to its maximum setting and the engines at full power, the cabin air ducts will overheat and emit smoke and fumes.

[Probst 67:16 – 68:4] Q. What did he do to purposely try to cause the problem?

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[5] Logbook entry dated June 24, 2011, Bates stamped DAVIDSON V. ROCKWELL – Northrop 002174.

A. Well, we did a ground test. You know, we ran the aircraft on the ground and tried to create the smoke. And we were able to do that on the ground. It was a hot day. The duct work gets very hot. And if you go to a high temperature, you can cook the duct at any point. There's no problem, you can do it. If you're not careful, you can do it.

Q. How do you do it?

A. Turn up the heat all the way up. You have the air blowing on high heat. Have the engines running at full power. Oh, it'll cook the duct work every time on there.

Continuing with the August 1, 2011 logbook entry:

> Removed the ACM to inspect for any possible cause. When the end of the turbine duct was removed there were signs that the turbine had contacted the outer wall and also the tips of the turbine blades were slightly damaged. Installed overhauled ACM, part number 977018-1, S/N 0335 using a new gasket kit supplied with the unit. Installed new duct hose assemblies 880158-513. Ground test was good.[6]

Probst clarifies in deposition testimony that the issues discovered with the ACM described in the August 1, 2011 log entry did not indicate ACM oil leakage into the ECS:

[Probst 33:21 – 34:4] Q. The problem you found with the ACM on August 1st, 2011, where you talked about the turbine having contacted the outer wall and turbine blades being further damaged, could that cause any turbine engine oil to leak into the system?

A. The only thing that – no, I don't believe so. The only thing that would cause would be the ACM not to turn at the right speed. It would slow it down.

Continuing, the August 1, 2011 logbook entry indicates that this inspection did reveal additional issues with the cabin heating control components of the ECS:

> It was also discovered during the maintenance check that the cabin inlet duct temp was greatly affected when the auto temp control box was

[6] Logbook entry dated August 1, 2011, Bates stamped DAVIDSON V. ROCKWELL – Northrop 002175.

removed from the cabin wall. New insulation was added to confirm that the system was working normally.

After the August 1, 2011 ACM replacement, the cabin air smoke and fume events continued. Around December 2011 Eagle Creek Aviation Services, Inc., a Turbo Commander service center in Indianapolis, Indiana received reports of cabin air smoke and fumes and found the temperature control valve and rheostat to be defective.[7]

The FAA issues Airworthiness Directives (ADs) to correct unsafe conditions with aircraft, engines, propellers, and components. Compliance with ADs are mandatory in order to continue operating the aircraft or component of which the AD applies. A search for ADs on the FAA website, www.faa.gov resulted in no issued or proposed ADs for the incident model ACM.

According to evidence and testimony the Fairchild ACM was not a cause of the May 31, 2011 cabin air fume event.

In his expert report dated January 14, 2016, Don Hansen, M.E., P.E. (Hansen) opined that "leakage of turbine engine oil from and through the Fairchild ACM was the cause of the observed and dangerous oil fume emissions into the confined space of the cabin". In his analysis, Hansen supports his opinion with misinterpretation of evidence and testimony:

> "Both the original ACM and the overhauled ACM (Serial #0335) had evidence of oil leakage from the turbine side and the impeller side of the rotor (ref. doc. PAI-8) thus indicating ACM oil seal leakage."[8]

The reference document PAI-8 is a copy of pages 165 through 168 of Probst's deposition transcript. The document being discussed at this point in the deposition is Fairchild Shop Visit Report of ACM serial number 0335 Bates stamped DAVIDSON V. ROCKWELL – Northrop 002190. The 0335 serial number ACM was installed on the Aircraft on August 1, 2011, two months AFTER the May 31, 2011 cabin air smoke and fume event. The ACM that was on the Aircraft on May 31, 2011 was removed by Probst on August 1, 2011 and replaced by ACM serial number 0335. There is no evidence that Probst recorded the removed ACM serial number, but testified that it had no evidence of oil leakage.

[Probst 167:3 – 167:9] Q. So consistent with that, doesn't it make sense that

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[7] Eagle Creek Aviation Services, Inc. Invoice, item 008, Bates stamped EC 000055.

[8] Expert Report of Don Hansen, M.E., P.E., page 5 of 18.

there would have been oil leakage from both the turbine side and the propeller side of the rotor in the original ACM that was in the aircraft on May 31, 2011?

A. If there were any evidence of it, yes. But there was no evidence of it anywhere.

On page 5 of his report, Hansen criticizes the aircraft maintenance manual for not providing pilots or mechanics with instructions to determine if excess turbine oil is inside the Fairchild ACM. By virtue of the design of the ACM's oil compartment, the correct amount of turbine engine oil puts the oil level at the very top of the fill tube. Any attempt to add more oil than the specified 2.5 fluid ounces results in the excess oil overflowing the tube. This design feature makes it virtually impossible to add too much oil.

On page 6 of his report, Hansen theorizes that the ACM is a possible source of oil that can mix with and contaminate the cabin air, but fails to establish that the incident ACM did leak oil and was a cause of the May 31, 2011 cabin air fume event.

Don Hansen's analysis is flawed as it failed to show evidence that the incident ACM was leaking oil and emitting smoke and fumes into the Aircraft cabin during the event on May 31, 2011.

Don Hansen's analysis is flawed as it failed to include evidence that the Aircraft heat ducts were overheating and emitting smoke into the Aircraft cabin.

On page 4 of his report, Hansen claims:

> Unfortunately, the only way for "clean" outside air to arrive within the cabin is through the Fairchild ACM (Bates # CD03832 & 384747 & PAI-12c), and this airway has no filters or absorbers.

The ECS schematic he provides as Figure 6 of his report (see Figure 1 of this report) is contrary to his claim. In actuality, compressed hot air from the jet pump assembly bypasses the ACM and enters the air plenum via the hot air valve during high altitude operations where cabin heat is commanded by the pilot control. Therefore, <u>any</u> attempt to install or integrate fume sensors, filters, absorbers, and/or suggested diverters into the ACM will fail to prevent cabin air smoke and fume events caused by either contaminated engine bleed air or overheated heat ducts. For this reason, airframe manufacturers install cabin air filtration downstream of the refrigeration units, heating ducts and mixing plenums. Hansen failed to site any examples of aircraft that

use the air cycle machine, regardless of design, make or model as the means of filtration for the cabin air system. Nor can I.

Don Hansen's proposed alternative design of fume sensors, filters, absorbers, and/or suggested diverters within the Fairchild ACM is unproven and would fail to warn or protect the Aircraft occupants from toxic engine bleed air entering the cabin.

Under the paragraph "Alternative systems capable of preventing the claimant's damage (which would not be unduly burdensome to anyone) were/are available", Hansen lists that Fairchild could have used oil-less bearings in their ACM and suggests "some FAA Supplemental Type Certificate (STC)" as a means to do so. I am familiar with the STC process. To endure this process and be granted an STC from the FAA is anything but "unduly burdensome". Furthermore, in order to convert the Fairchild ACM from oil lubricated bearings to oil-less bearings, a redesign of the entire unit would be required.[9]

Don Hansen's proposed alternative design of using oil-less bearings in the Fairchild ACM would be unduly burdensome to Fairchild and would require a complete redesign of their ACM.

Even aircraft ECS that do not incorporate an oil-lubricated ACM still suffer from contaminated engine bleed air entering the cabin. Thomas Farmer claimed that the Peter Schiff STC which replaces the entire ECS in the 690A is the answer to eliminate cabin smoke and fume events in the Aircraft. This system uses the engine bleed air to pressurize fresh outside ram air, eliminating compressor bleed air from entering the cabin. Yet, even that system still incorporates oil-lubricated bearings in the "special turbocharger"[10], evidence that the more likely source of smoke and fumes in the 690A aircraft cabin is engine bleed air and not the ACM. Hansen agrees. On page 6 of his report he references the engine maintenance manual in his statement:

> "The hot "bleed" air leaving the engines contains oil particles because Garrett Engines normally leak (ref. doc. PAI-1b)."

Don Hansen's proposed alternative design of replacing the ACM's oil lubricated bearings with oil-less bearings would fail to protect the Aircraft occupants from toxic engine bleed air entering the cabin.

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[9] Declaration of Paul Dziorny, Fairchild Vice President, Chief Engineer, paragraph 17, 18.

[10] http://www.peterschiffaero.com/#toxic

6.0 FINDINGS

Within the bounds of reasonable technical and professional certainty, and subject to change if additional information becomes available, it is my opinion that:

6.1 According to evidence and testimony the Fairchild ACM was not a cause of the May 31, 2011 cabin air fume event.

6.2 Don Hansen's analysis is flawed as it failed to show evidence that the incident ACM was leaking oil and emitting smoke and fumes into the Aircraft cabin during the event on May 31, 2011.

6.3 Don Hansen's analysis is flawed as it failed to include evidence that the Aircraft heat ducts were overheating and emitting smoke into the Aircraft cabin.

6.3 Don Hansen's proposed alternative design of fume sensors, filters, absorbers, and/or suggested diverters within the Fairchild ACM is unproven and would fail to warn or protect the Aircraft occupants from toxic engine bleed air entering the cabin.

6.4 Don Hansen's proposed alternative design of using oil-less bearings in the Fairchild ACM would be unduly burdensome to Fairchild and would require a complete redesign of their ACM.

6.5 Don Hansen's proposed alternative design of replacing the ACM's oil lubricated bearings with oil-less bearings would fail to protect the Aircraft occupants from toxic engine bleed air entering the cabin.

Respectfully submitted,

Matthew D. Lykins AP, IA

STATE OF TEXAS
BARTLEY J. ECKHARDT
111829
LICENSED
PROFESSIONAL ENGINEER

MATTHEW D. LYKINS
Aviation and Mechanical Expert

Experienced in safe private and commercial operations, management, training, maintenance, modification, troubleshooting, repair, overhaul, upgrade and certification, of both fixed-wing and helicopter aircraft and their equipment and systems.

Aircraft (Airframe) Inspections, Operations, Repair, Maintenance, Troubleshooting, Recertification: Airframe electrical including lighting and caution and warning systems, landing gear systems including electrical, hydraulic, emergency extension systems, flight controls systems – manual, electrical, and hydraulic including proper installation and rigging, structural repair processes – sheet metal, wood and composites, breathing oxygen systems, cabin pressurization systems, cabin heating, cooling, and ventilation. Aircraft refueling operations, de-fueling, fuel sampling and testing for contamination / quality, fueling safety procedures and standards.

Aircraft (Power Plant) Inspections, Operations, Repair, Maintenance, Troubleshooting, Recertification: Engine electrical and electrical power generation and control, engine ignition systems, engine mechanical, engine fuel scheduling and management systems including carburetors, fuel injection, turbo-charging, turbine engine hydro-mechanical and electronic fuel controls, engine oil systems, engine cooling systems, engine induction and exhaust, auxiliary power units (turbine), propeller and governor systems including feathering and reversing systems, engine and airframe fire detection and extinguishing systems including continuous loop type and High Rate of Discharge (HRD) extinguishing systems, low-thrust detection and warning systems on multi-engine aircraft, propeller and rotor dynamic balancing.

Aircraft (Avionics / Electronics) Inspections, Operations, Repair, Maintenance, Troubleshooting, Recertification: Avionics, digital flight instrumentation, integrated navigation / communication systems, GPS, auto-pilot systems, electronic engine monitoring and management systems including FADEC, glass cockpit.

Material Handling / Lift Equipment: Safety inspections, operations, repair, maintenance, and troubleshooting of hydraulic and pneumatic systems, components, and controls, guards and safety features, on lift vehicles including lift trucks, lift gates, loading dock levelers, forklifts, fork trucks, scissor lifts, pallet jacks, and boom lifts.

Agricultural Machinery / Grain Elevator Equipment: Machinery and equipment failures and malfunctions. Agricultural accidents and farm operation issues. Safety inspections, operations, repair, maintenance, and troubleshooting of heavy duty tractors, tillage discs, harvesters, plows, cultivators, mowers, gravity wagons, grain trucks and trailers, grain augers, drills, planters, sprayers and grain elevator dumps, pits, scales, legs, augers, bin sweeps, grain dryers, feed grinders and hammer mills.

MATTHEW D. LYKINS
Aviation and Mechanical Expert

Tools: Hydraulic jacks and lifts, hoists and slings, raised work stands, engineered work platforms, ladders, bench grinders, rotary pneumatic drills, drill presses, impact wrenches, welders - acetylene, Metal Inert Gas (MIG), Tungsten Inert Gas (TIG), pneumatic rivet guns, compression testers, multi-meters, crimpers, band-saws, lathes, hydraulic presses.

Technical / Vocational Training and Teaching: Classroom lecture / instruction, shop / lab training and supervision, tool equipment usage training and evaluation, shop floor safety, school lab and shop safety, student progress and evaluation, engine start-up and operation training, test administration, student advisement, course development, Federal Aviation Administration (FAA) approved training program development.

Safety Procedures and Requirements: Shop floor safety, development and enforcement of safety policies and procedures, material safety data sheets (MSDS), right-to-know, lockout / tag-out, operational guards, caution and warning signs, instruction manuals, training, airport ramp and ground operations procedures including aircraft towing and tow vehicles, ground support vehicles, baggage handling equipment, jet-ways, air-stairs, single point and over-wing refueling equipment, flight line operations procedures including aircraft marshalling and signaling during day and night conditions, aircraft run and taxi, flight line maintenance operations, and maintenance flight procedures, forklifts, forklift operations, material handling.

Certification Processes: FAA Certified Repair Station (Part 145), FAA Certified Air Carrier (Part 135 / 121), FAA Certified Airframe and Power-Plant Technician School (Part 147), FAA Designated Mechanic Examiner – testing for and issuing of FAA aircraft mechanic certificates.

Inspection and Testing: Non-destructive Examination (NDE) / Non-destructive Testing (NDT), aircraft inspection programs – annuals, 100 hour, progressive, FAA Approved Aircraft Inspection Programs (AAIP), altimeter, pitot-static and transponder tests and inspections, emergency locator beacon (ELT) tests and inspections, pre-purchase evaluations, special flight permit (ferry permit) inspections.

PROFESSIONAL EXPERIENCE

2010 to present — **Robson Forensic, Inc.**
Associate
Provide technical investigations, analysis, reports, and testimony toward the resolution of commercial and personal injury litigation involving maintenance shops, associated tooling and equipment, aircraft ground operations, training and technical school environment, aircraft systems and product failure analysis.

MATTHEW D. LYKINS
Aviation and Mechanical Expert

2015 to present — **Matthew Avionics Testing & Technical Support, LLC** Stevensville, MT
Owner / Accountable Manager
FAA certified repair station specialized in avionics systems tests, inspections and re-certifications.
Provide in-field technical support to helicopter and fixed-wing operators including wildfire helitack, aerial utility crews and aerial spraying operators in remote locations.

2014 to present — **ARGUS International, Inc.** Greenwood Village, CO
Aviation Safety Auditor
Conduct worldwide IS-BAO (International Standard for Business Aircraft Operations) audits of domestic and international business aviation operators.
Conduct worldwide ARGUS audits of domestic and international business aviation operators

2009 to present — **Matthews Aerospace Training and Technical Support (M.A.T.T.S.)**, Franklin, IN
Founder and President
Consulting, Training (DME), and Aircraft Maintenance Services

- Develop and consult aerospace company management on 14 CFR 145 FAA certified repair station application process, which includes Statement of Compliance, Repair Station Manual, Quality Control Manual, Training Program, and all repair station forms and instructions for use of each form.
- Provide expert technical and flight support for real-time in-flight emergencies involving aircraft mechanical failures directly affecting the safe termination of a flight. (24/7 availability) This includes direct communication in real-time with FAA air traffic controllers, the flight crew on board the affected aircraft, aircraft manufacturer technical support staff, as well as direct airborne support as necessary to evaluate the extent of the problem and assist the pilot in command in executing all possible procedures to get the aircraft on the ground safely.
- Provide aircraft maintenance facilities, repair personnel, and aircraft owners with critical troubleshooting and repair support and training as necessary for unusual failures on the various aircraft systems.
- Perform pre-purchase evaluations on aircraft prior to a sales transaction. This includes mechanical, operational, flight, and documentation evaluations, which are all detailed on a pre-purchase evaluation report that is provided to the perspective buyer and the seller.
- Apply for and obtain from the FAA special flight permits for aircraft needing flown to another location for necessary maintenance affecting airworthiness. Inspect these aircraft for safe flight under the permit. Fly the aircraft under the permit to the maintenance location as needed.

- Consult aircraft owners and operators on technical matters including special maintenance items and equipment upgrades to their aircraft. This often includes a feasibility study.
- As a FAA Designated Mechanic Examiner for the past 12 years, provide FAA testing and final evaluation of Airframe and Power Plant Mechanic applicants. Issue FAA Form 8040-4 Temporary Airmen Certificate to those who successfully complete the testing process.

2009 to present **Aviation Institute of Maintenance**, Indianapolis, IN
Instructor, Airframe and Power Plant
Teach as an aviation technical instructor for the following subject areas for a FAA Approved Part 147 school. This includes training through lecture, lab projects and research on theory, application, operation, fabrication, repair, overhaul, troubleshooting, inspection, standards of airworthiness, major and minor repair design of airframes, power plants, and systems, major and minor alterations of airframes, power plants, and systems, failure prediction and forecasting, identification and reporting of faults, malfunctions, failures, and design defects:

A. Basic Electricity, both AC and DC theory
B. Aircraft Drawings and Blueprints
C. Weight and Balance
D. Fluid Lines and Fittings
E. Materials and Processes
F. Ground Operations and Servicing
G. Cleaning and Corrosion Control
H. Mathematics
I. Maintenance Forms, Records, and Federal Aviation Regulations
J. Physics
K. Maintenance Publications
L. Aviation Mechanic Privileges and Limitations
M. Wood Structures
N. Aircraft Coverings
O. Aircraft Finishes
P. Sheet-Metal and Non-Metallic Structures
Q. Welding
R. Assembly and Rigging
S. Airframe Inspection and Troubleshooting
T. Aircraft Landing Gear Systems
U. Hydraulic and Pneumatic Power Systems
V. Cabin Atmosphere Control Systems
W. Aircraft Instrument Systems
X. Communication and Navigation Systems
Y. Aircraft Fuel Systems
Z. Aircraft Electrical Systems
AA. Position and Warning Systems

BB. Ice and Rain Control Systems
CC. Fire Protection Systems
DD. Reciprocating Engines Theory and Operation
EE. Turbine Engines Theory and Operation
FF. Engine Inspection and Troubleshooting
GG. Engine Instrumentation Systems
HH. Engine Fire Protections Systems
II. Engine Electrical Systems
JJ. Lubrication Systems
KK. Ignition and Starting Systems
LL. Fuel Metering Systems
MM. Engine Fuel Systems
NN. Induction Systems
OO. Engine Cooling Systems
PP. Engine Exhaust and Turbo-Charging Systems
QQ. Propellers
RR. Turbine Powered Auxiliary Power Units

1999 to 2009 **Skyward Air Service, LLC, Seymour, IN**
Founder and President

- Acquired FAA Part 135 Air Carrier Certification, Director of Maintenance for Part 91 and Part 135 aircraft
  - Aircraft acquisitions
  - Maintenance Program development and implementation
  - Pilot and crew hiring, training, evaluation, scheduling
  - Managing personnel issues and concerns
  - Marketing charter business
  - Coordinating all aspects of the charter business with the FAA including FAA inspections and audits
  - Developed and implemented FAA Drug and Alcohol Abatement Program
- Acquired FAA Part 145 Repair Station Certificate
  - Equipment acquisitions and calibration tracking
  - Personnel hiring, training, and development
  - Pitot-Static, transponder, and altitude reporting equipment tests and inspections as a repairman with return-to-service authorization
- Performed avionics and instrumentation system upgrades.
- Troubleshot electronic, navigation, communication, engine monitoring systems including airframe electrical systems on aircraft.
  - All Cessna single-engine and multi-engine piston aircraft
  - All Piper single-engine and multi-engine piston aircraft
  - All Beechcraft single-engine and multi-engine piston aircraft
  - All Grumman single-engine piston aircraft
  - All Mooney single-engine piston aircraft

- Bellanca Viking series aircraft
- All American Champion aircraft
- All Diamond DA20, DA40, and DA42 diesel aircraft
- Cirrus single-engine piston aircraft
- Various experimental / homebuilt single-engine piston aircraft
- Cessna Citation 500, 501, and Bravo turbine aircraft
- Lear 24, 25, 35 turbine aircraft
- Beechcraft King Air 90, 100, and 200 turboprop aircraft
- Bell 47 piston helicopter
- Bell 206 turbine helicopter

- Coordinated maintenance scheduling with aircraft owners/operators and the maintenance department.
- Built job estimates for scheduled, unscheduled, and upgrade maintenance projects.
- Managed maintenance projects from start to finish.
- Performed pre-purchase evaluations on all aircraft listed in paragraph (f) above for perspective buyer anywhere in the U.S.
- Performed annual, 100 hour, progressive, daily, and phase inspections (as required) on aircraft listed above.
- Performed the required repairs and servicing (including major airframe and power plant repairs and alterations) to aircraft listed above.
- Developed and enforced company policy and procedures.
- Provided consulting services to airport management regarding security, emergency procedures, standards, and events.
- Managed aircraft fueling operations including fuel farm operations and maintenance, filtration, fuel quality and purity testing and monitoring, refueling equipment operations and maintenance, training fueling and line personnel in policy, procedures, safety, quality and standards for aircraft refueling operations.

1999 to 2000 — **American Trans Air**, Indianapolis, IN
Instructor, Maintenance Training
Provided on-site advanced training to line and overhaul technicians at Indianapolis and out-stations regarding the Boeing 757, Boeing 727, and Lockheed L-1011. Developed new courses for advanced composite structural repairs to the Boeing 727, 757, and Lockheed L-1011 aircraft.

1998 to 1999 — **American Trans Air Training Academy**, Indianapolis, IN
Instructor
Aviation technical instructor for the following subject areas for a FAA Approved Part 147 school. This included lecture, labs, research projects, and troubleshooting scenarios with class sizes ranging from 5 to 25 students.

MATTHEW D. LYKINS
Aviation and Mechanical Expert

1995 to 1998 **Aero Tech, Inc.**, Danville, KY
A&P Mechanic
Serviced, repaired, rebuilt, and maintained general aviation aircraft under part 91 and 135. Performed daily aircraft refueling operations including fuel farm operations, refueling safety and emergency procedures, single point and over-the-wing refueling of fixed-wing and rotorcraft, fuel sampling and quality testing and record keeping.

1985 to 1995 **Lykins Farms**
Agriculture Heavy Equipment Operation, Maintenance, Safety

- Partnership grain farming operation with father. Grain enterprise included 2000+ acres of corn / soybeans and family owned and operated grain elevator with a focus on specialty mixes of livestock feeds and supplements. Operated, serviced, repaired, rebuilt, and maintained heavy duty tractors, tillage discs, harvesters, plows, cultivators, mowers, gravity wagons, grain trucks and trailers, grain augers, drills, planters, sprayers in addition to smaller miscellaneous farm tools and equipment.
- Managed the safe transport, control, and application of herbicides, pesticides, and fertilizers including ammonium nitrate.
- Operated and maintained center-pivot irrigation systems including on-site diesel power generators and corner design systems.
- Grain elevator maintenance and safety inspections of dumps, pits, scales, legs, augers, bin sweeps, grain dryers, feed grinders and mills.

PROFESSIONAL CREDENTIALS

Infrared Thermographer – Level 1 Certification April 2012
Society of Professional Rope Access Technicians – Level 1 Certification March 2012
FAA Repairman Certification, 2005-2009
FAA Designated Mechanic Examiner, since 1998
FAA Inspection Authorization, since 1997
FAA Mechanic Airframe and Power plant, since 1990
FAA Pilot Certificate, since 1990
  Commercial rating
  Instrument
  Multi-engine
  High performance endorsement
  Over 1500 flight hours logged

EDUCATION

MATTHEW D. LYKINS
Aviation and Mechanical Expert

Bachelor of Science, Aviation Maintenance Technology, Purdue University, 1995
Minor: Composite Technology; Minor: Management/Supervision
Associate of Science, Aviation Maintenance Technology, Vincennes University, 1991
FAA Airframe and Power-plant Certificate with Inspection Authorization

PROFESSIONAL MEMBERSHIPS

Lawyer-Pilots Bar Association
Aircraft Owners and Pilots Association
Experimental Aircraft Association

AWARDS

FAA Maintenance Technician of the Year 2005

INVITED TALKS

Maintaining GA Aircraft – By the Book?, Lawyer Pilots Bar Association, Summer meeting 2012, Williamsburg, VA

PUBLICATIONS

Lykins, M.D., *Keep Those Ole Magnetos Flying,* Lawyer Pilots Bar Association Journal (Winter 2012)
Lykins, M.D., *What's A FAA Form 337? I'm the Owner – Not an Aircraft Mechanic,* Lawyer Pilots Bar Association Journal (Fall 2012)

OTHER

Eagle Scout, 1988
Missionary Service, 1991-1993
Bi-lingual: English and Spanish

BARTLEY J. ECKHARDT, P.E.
Marine and Mechanical Engineer

Experienced in the design, installation, testing, startup, safe operation, maintenance, modification, troubleshooting, upgrade and repair of marine and industrial machinery, equipment and systems.

Manufacturing Processes: General machining, metal forming, welding, brazing, grinding, soldering, oxyacetylene cutting, metal flame spraying, aligning, shrink fitting, slitting, composite laminating, blending, drying, liquid and dry filling, dedusting, dry solids handling, slurry handling, liquid handling, paint preparation, painting.

Piping and Pressure Vessels: Piping and Pressure Vessels (vacuum up to hydraulic pressures) – pipe welding and threading, flanges, butt-weld fitting, socket weld fittings, thread-o-let, sock-o-let, ASME B31.1 and B31.3, ASME Sections VIII and IX, National Board inspection Code (NBIC) requirements, ASME Code stamping – fired, unfired and repaired pressure vessels, piping supports, insulation, inspection, fouling, corrosion, failure analysis, methods for working pipelines live, use of saddles, blind flanges, spectacle flanges, bypass and blanking fittings such as pigs, stopples, plugs, methods for damage control and emergency repair methods, Non-destructive Examination (NDE) techniques.

Manufacturing Procedures, Standards and Specifications: Pressure vessels, power piping, pipe welding, structural welding, international steel specifications, sanitary manufacture, pharmaceutical manufacture, drawing standards, hazardous area requirements.

Testing methods and specifications: Hydrostatic testing, mil-spec shock and vibration testing, static and high speed dynamic balancing, acceptance sampling, material testing, thermal mapping, standpipe, sprinkler and inert gas fire system testing.

Management systems and standards: Quality systems and performance sampling.

Engineered Systems: Steam, condensate, feedwater, liquid fuel systems, aircraft refueling, natural gas, process water, potable water, deionized water, refrigeration, salt water service, ballast, tanker cargo, fire protection, waste water, hydraulic power, pneumatic power, pneumatic control, heating, ventilating and air conditioning, clean room, vacuum, exhaust, high pressure tree spraying, commercial laundry.

Machinery: Diesel engines, high-speed centrifuges, cable winches, pumps, drive gears, clutches, compressors, distillers, heat exchangers, chillers, cooling towers, air handlers, valves, boilers, turbines, jib cranes, monorail cranes and hoists, overhead bridge cranes, milling machines, lathes, slitters, presses, check weighers, screw conveyors, belt conveyors, roller conveyors, spreader beams, lifting and rigging gear, v-blenders, pony mixers, hammermill grinders, glue dispensers and applicators, reciprocating die cutters and perforators.

Machinery Safeguarding: Safety interlocks, drive guards, operational guards, pinch point guards, failsafe modes, caution and warning signs, instruction manuals.

BARTLEY J. ECKHARDT, P.E.
Marine and Mechanical Engineer

Safety Procedures and Requirements: EMS, material safety data sheets, right-to-know, confined space entry, lockout/tagout, high-rise scaffold, training, policies, inspections, OSHA requirements.

Tools: Reciprocating pneumatic hammers, rotary pneumatic drills and impact wrenches, gas-powered chain saws.

Buildings: Facilities systems, hospital systems, prison systems, façade pinning, fire protection, code conformance, inspections, industrial and domestic hot water systems, water and chemical mixing, eduction, pressure spraying, tempering, and injection. Preserving fire protection during construction, renovation and demolition. Monitoring and supervision of inspection, repair, testing and certification of gas and water fire protection including standpipes, sprinklers and inert gas systems.

Products: Bicycles; motorboats and associated equipment; jet skis, wave runners, sailboats and associated equipment; canoes, rowboats, kayaks and associated equipment; grating, diamond plate and catwalks.

Regulatory Compliance: Pharmaceutical validation, air quality permitting, New York City permitting.

PROFESSIONAL EXPERIENCE

2001 to present — **Robson Forensic, Inc.**
President and CEO 2006-present
Midwest Operations Manager 2004-2006
Ohio Area Manager 2001-2004
Provide technical investigations, analysis, reports, and testimony toward the resolution of litigation involving marine, manufacturing and other mechanical engineering issues.

2001 to present — **Fournier, Robson & Associates, LLC**
Associate
Provide specialized mechanical engineering for buildings, machinery, products and systems.

1995 to 2001 — **Technology Development, Inc.** Specialty Engineering
President and Owner
Engineering and troubleshooting of highly specialized machinery, products and systems. Developed several portable process plants; developed slitters and modified 200 ton pod presses for the manufacture of structural composites; executed validation

of pharmaceutical products and processes to FDA requirements; developed proprietary products and processes for structural composites and laminates; developed proprietary distillation processes for vitamin and flavor intermediates; engineered liquid, gas and mechanical systems for a huge commercial laundry; designed HVAC systems for archive preservation; refined testing and sampling criteria for façade pinning; modified tub grinders for life extension of the hammers. Reversed engineered and manufactured large buffer carriage assemblies for the Staten Island Ferry. Taught power plant operations and safety courses; executed evaluations of design, maintenance, operational and/or construction defects in power plants for New York Department of Corrections.

Mid-rise and high-rise "arm's length" façade and roof inspections. Design and site monitoring of mid-rise and high-rise demolition and renovation projects in New York City, including maintaining life safety provisions such as fire protection and security during demolition, construction, roofing and hot work. Instructed power plant and facilities engineers in the risks of hot work, proper explosive gas venting, maintenance of fire protection systems and proper use of fire watches.

1983 to 1995 — **Centrico, Inc.** — Turnkey Systems Manufacturer
Director of Engineering
Managed the design, test and quality of custom turnkey process systems, usually incorporating high speed centrifuges, pumps and heat exchangers; Developed the high pressure (1000 psig) fuel injection system for the world's largest gas turbine; developed the first steam sterilizable system for cell separation for injectables; developed systems for sophisticated military centrifuges to international requirements; evaluated equivalency of numerous European steels with U.S. standards; developed engineering procedures for ISO 9000 compliance; developed weld procedures to ASME IX and AWS D 1.1; engineered systems for pharmaceutical, marine, power, food, biotechnology, and petrochemical applications in accordance with appropriate industry standards; developed rigging beams, hoists, and rigging schemes for installation of large systems; developed a test stand and related procedures for hydrostatic testing of elaborate systems; developed thermal mapping method to ensure "kill" temperatures in elaborate biotech systems; evaluated methods for static and dynamic balancing, internally and externally excited vibration; provided seismic analyses as required.

1979 to 1983 — **U.S. Merchant Marine** — Ship Design and Operations
Engineering Officer
Various assignments as engineer aboard ocean-going tugboats, an oil exploration drillship, and the Training Ship Empire State; taught basic marine engineering, ran thermo and fluid labs, taught machine shop (turning, milling, welding, grinding), ran strength of materials labs; worked as a senior marine engineering consultant with M.

Rosenblatt & Son, Inc. in the basic ship design and mechanical groups. Executed designs of inert gas and wet fire protection systems. Supervised hot work and fire watches and put plans in place for emergency fire protection during maintenance and repair activities.

PROFESSIONAL CREDENTIALS

Professional Engineer, NCEES, New York, Kentucky, Pennsylvania, Alabama, West Virginia, North Carolina, Michigan, New Jersey, Florida, Minnesota, Delaware, Connecticut, Illinois, Maryland, Iowa, Kansas, Oklahoma, Tennessee, Texas, South Carolina, Wisconsin
Chief Engineer (Limited-Near Coastal), Motor/Gas Turbine Vessels, Unlimited Horsepower (2005-2010)
Second Assistant Engineer, Motor/Gas Turbine Vessels, Unlimited Horsepower (1982-2010)
Third Assistant Engineer, Steam Vessels, Unlimited Horsepower (1979-2010)
Designated Duty Engineer of Steam, Motor/Gas Turbine Vessels, Unlimited Horsepower (2005-2010)
OS (Ordinary Seaman) (1979-2010)
SD (FH) (Steward Department [Food Handler]) (2005-2010)
Any Unlicensed Rating in Engine Department (1979-2010)
LBMAN (Lifeboatman) (1979-2010)
STCW-95 (Standards for Training, Certification, and Watchkeeping for Seafarers) (2005-2010)
Honorable Discharge, Lieutenant, U.S. Naval Reserve (1989)

EDUCATION

B.E. Marine Engineering, SUNY Maritime College at Fort Schuyler, 1979

Continuing Coursework and Seminars:
The Mason & Dixon Historical Track 2015:
The Great English Chancery Suit - Penn v. Calvert
Mason & Dixon's Survey, and the True "Stargazer's" Point
Searching for Philadelphia's Southernmost Point
Jeremiah Dixon, Surveyor of Durham, England
Restoring Mason & Dixon's 1760 Transit and Equal-Altitude
Elements of Machine Design, 2015
An Engineer's Approach to Designing a New Building, 2015
Use of Engineering Seals and Stamps in NY Avoiding Professional Misconduct, 2015

BARTLEY J. ECKHARDT, P.E.
Marine and Mechanical Engineer

An Anthology of Security Technology in the Age of Terrorism & Natural Disaster, 2015
Introduction to Combined Cycle Power Plants, 2015
The Basics and Interpretation of Mechanical Failure, 2015
Ethical Decision Making for Engineers IV, 2015
Designing DC Systems for Troublefree Operation, 2015
Inland Waters Rescue and Survival, 2014
Centrifugal Pumps – Components, Operation and Energy Conversion, 2014
Reliability Engineering Fundamentals, 2014
Hydraulic Accumulators – An Introduction, 2014
Air Compressors, 2014
Ethical Decision Making for Engineers II & III, 2014
ASME/USCG Workshop on Marine Technology and Standards Panel: Human Element and Risk Management, 2013
SNAME Technical Session in Institutionalizing Modular Adaptable Ship Technologies, 2012
ASME International Engineering Congress & Expedition, Technical Sessions in Product Design, Equipment, Machine and Manufacturing, 2012
Ethical Decision Making for Engineers I, 2012
Steam Turbines, 2011
Thermodynamics I: An Introduction, 2011
Heavy Construction Equipment Basics – Lifting, 2011
Introduction to Rain Gardens, 2011
Steam System Basics & Performance Improvements, 2011
Preventing and Investigating Accidents, 2010
OSHA Demolition, 2010
Safety: Fire Part 2 – Fire Protection Equipment & Techniques, 2010
Safety: Fire Part 1 – Workplace Fire Hazards & Preventing Fires, 2010
Site Safety Risk and Liability, 2010
The Need for Additional Human Factors Considerations in Ship Operations, 2010
Technology and Applications for Subsurface Imaging in Construction, 2009
Ex Situ Remediation Technologies for Contaminated Soils, 2009
Renewable Energy Generation, 2009
OSHA Safety: Drilling, 2009
Plumbing: Lead Work, Silver Brazing & Soft Soldering, 2009
Petroleum Engineering: Liquid Process Piping – Introduction and Design Strategy, 2009
Fuel Cell Power Systems, 2009
Petroleum Engineering: Liquid Process Piping – General Piping Design, 2008
Swimming Pools: Mechanical and Hydraulic System Design, 2008
Coastal Engineering: Storm Surge, 2008
Coastal Engineering: Sea Level Rise, 2008
Coastal Engineering: Hurricanes – The Basics, 2008
In Situ Remediation Technologies for Contaminated Soils, 2008

Pipe Support Systems, 2008
Maritime Accident Investigation Analysis and Reconstruction – 40 Hours – World Maritime University
Engineering Ethics I, P.E.C.E. lecture, 2007
Marine Fuels: Specifications, Testing, Purchase and Use, ASTM training, 2007
Major Testing Techniques for Plastics, ASTM training, 2007
EMD Diesel School Certificate
New York State lockout/tagout and confined space training
Offshore helicopter refueling training
ISO 9000 auditor training
Naval Officer training in ship's shoreside maintenance, NBC defense
Kayak self-rescue course, Shank's Mare, Pennsylvania, 2006

PROFESSIONAL MEMBERSHIPS and AFFILIATIONS

Towing Safety Advisory Committee Subcommittee TASK #14-01: Review of and recommendations based on the Report of Investigation into the Grounding of the Mobile Offshore Drilling Unit (MODU) KULLUK. Subgroup Leader.

Subgroup B: Tow Gear-Identification, selection, testing, utilization, monitoring, and logging.

Examine and prescribe technical standard and best practices for ocean tows of MODU's or vessels of a similar nature to include towing equipment, identification and logging of the use of this equipment, inspection regimes to include trip-in-tow and warranty surveys and non-destructive testing of towing equipment prior to tows. Development of technical standards should include review of existing primary source standards such as the U.S. Navy Towing Manual.

Examine and prescribe a process for the issuing of tracking certificates that accompany towing hardware. The process of issuing and tracking certificates that accompany towing hardware to include identifying a particular component by a standardized tracking method currently in review in TSAC Task Statement 13-06 - Towing Gear and that product to be formally incorporated and referenced into the KULLUK TSAC 14-01.

Evaluate usage and application of strain monitoring devices equipped on towing vessels to determine the recommended procedures to reduce the likelihood of towing equipment failures. Examine the correlation between

catenary and the information provided by strain monitoring devices to effectively provide safety in towing operations.

Provide any other recommendations to the Coast Guard that the Committee feels is appropriate for this subject matter.

Tow gear includes, but is not necessarily limited to, towing winches, strain monitoring devices, riding leads and surfaces, wire rope, fiber rope, thimbles, sockets, shackles, pear links, chain, pendants, bridles, SMIT brackets, and flounder plates.

Towing Safety Advisory Committee Subcommittee TASK #13-06: Recommendations for Maintenance, Repair, and Utilization of Towing Equipment, Lines and Coupling. Member (Public)

Provide Recommendations to the Coast Guard on specific criteria to be used in determining the proper utilization of towing equipment for specific towing evolutions to include:

a. Standards for towing system capability.
b. Towing systems compatibility with the tow in regards to:
    I. Operational environment; and
    II. Expected forces exerted on the towing equipment
    III. Sufficiency of fail-safes for redundancy and tow retrieval

Provide recommendations to the Coast Guard on specific criteria for the care and maintenance of towing equipment to include repairs, frequency of maintenance and criteria for removal from service.

Provide recommendations to the Coast Guard concerning the specific knowledge, skills and training of persons responsible for the maintenance, repair and determination of towing gear for establishing a tow.

Member, SUNY Maritime College Engineering Advisory Board
ASME (American Society of Mechanical Engineers)
ABYC (American Boat and Yacht Council)
SNAME (Society of Naval Architects and Marine Engineers)
IAMI (International Association of Marine Investigators)
ASTM (American Society for Testing and Materials)
American Bar Association (ABA), Tort Trial & Insurance Practice Section-
Admiralty and Maritime Law Committee

*Towing Safety Advisory Committee (TSAC): (*Excerpted from Bylaws*)

The Towing Safety Advisory Committee (hereafter Committee) was established in 1980 by statute, the Act to establish a Towing Safety Advisory Committee in the Department of Transportation, Public Law 96-380.....

The purpose of this Committee is to act solely in an advisory capacity to the Secretary of the Department of Homeland Security (DHS), hereinafter referred to as "Secretary", on matters relating to shallow-draft inland and coastal waterway navigation and towing safety. The Committee is to advise, consult with, and make recommendations reflecting the Committee's independent judgment to the Secretary on these matters and actions. Finally, the Committee is to accept specific assignments and to conduct studies, inquires, workshops and fact finding **in consultation with individuals** (emphasis added) and groups **in the private sector** (emphasis added) and/or with State and local government jurisdictions in compliance with FACA to develop solutions.

PATENT

In-situ process for the remediation of contaminated soil

PUBLICATIONS and PRESENTATIONS

Co-authored paper "Towing Vessel Safety: Risk Based Management and Inspection of Towing Vessel Machinery Systems" for the ASME/USCG Workshop on Marine Technology and Standards, 2013

Engineering Lessons Learned – Mechanical and Industrial. Instructed at the Pennsylvania Society of Professional Engineers PDH Boot Camp, Eastern and Western PA, 2013 and 2015.

Eckhardt, B. J., Vigilante, W. J., Jr., & Coste, P. F., Visibility Factors in Small Boat Collisions. Presented at the *2012 International Marine Forensics Symposium.* National Harbor, MD: The Society of Naval Architects and Marine Engineers & American Society of Naval Engineers, 2012.

OTHER

Instructor in power plant operations and safety, New York State Department of Corrections and Office of Mental Health
Instructor in power plant operations and safety for offshore towboat operators

BARTLEY J. ECKHARDT, P.E.
Marine and Mechanical Engineer

Recreational Boater, 1960-present
EMT (Emergency Medical Technician), 1975-2002, Various Agencies
Co-author, U.S. Navy Towing Manual, 1983, (Under NAVSEA Contract)
Eagle Scout, 1971
Avid canoeist and sea kayaker

MATTHEW D. LYKINS

FOUR YEAR TESTIMONY HISTORY

Cindy Cunningham, as personal representative of the estate of Robert Cunningham, deceased v. Global Aviation, LLC; Estate of Armando Motta, deceased; and Frank Marsico; 2009-9258-CI-21, State of Florida in the Sixth Judicial Circuit Court for the County of Pinellas
Deposition: August 14, 2012

Everette Brown and Katia Brown v. Southeastern Aerial Crop Service, Inc.; 562012-CAD-002470, State of Florida in the Nineteenth Judicial Circuit Court of St. Lucie County
Deposition: September 5, 2013

Brock Gaudreault v. Elite Line services, LLC, G&T Conveyor Company, Inc.; 12-CV-01177 JNE/JJG, United States District Court District of Minnisota
Deposition: January 8, 2014

Jennifer Albright, Individually AND as Administratix of the Estate of Timothy Albright AND as Mother and Next Friend of Kailey Albright v. Alliance Coal, LLC, et al. and Warrior Coal, LLC and Alliance Coal, LLC vs. General Mine Contracting, Inc. and Cincinnati Insurance Company and Levee Lift, Inc. and Equipment Depot Kentucky, Inc. v. Troy Patterson and Matrix Design Group, LLC; 09-CI-1318 Consolidated with 10-CI-171 and 10-CI-446, Commonwealth of Kentucky Hopkins Circuit Court, Div 1 Madisonville, Kentucky
Deposition: January 10, 2014

AIG Europe Limited, f/k/a AIG UK Limited and Qatar Airways, Q.C.S.C. v. Gate Gourmet, Inc.; 2013-08229, State of Virginia in the Circuit Court of Fairfax County
Deposition: January 14, 2014

Willie Aviata vs. C&S Wholesale Grocers, Inc.; 11-1-0740-04 VLC, State of Hawaii in the Circuit Court of the First Circuit
Deposition: April 18, 2014

Equal Employment Opportunity Commission, and Safia Abdulle Ali, et. al vs. Jetstream Ground Services, Inc.; Civil Action No. 13-CV-02340-CMA-KMT; In the united States District Court for the District of Colorado.
Deposition: October 24, 2014

Dawn Workman vs. Executive Flight, Inc.; 13---2---00458---2, Superior Court of Washington for Douglas County
Deposition: March 31, 2015
Trial: April 17, 2015

Gloria Rodgers, Administrator of the Estate of John Rodgers vs. AWB Industries, Inc d/b/a Aircraft Tool Supply Company, McFarlane Aviation Inc.; 1:14-CV-00605-RBP; In the U.S. District Court for the Northern District of Alabama, Eastern Division.
Deposition: March 3, 2016

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF TEXAS
HOUSTON DIVISION

Kenneth Davidson, et al.,
Plaintiffs,

v. CASE NO. 4:15-cv-00827

Rockwell International Corporation, et al.,
Defendants.

EXPERT REPORT OF PAUL DZIORNY

A. Background and Qualifications

1. I am currently employed as Vice President, Chief Engineer at Triumph Thermal Systems—Maryland ("TTSM"), a Triumph Group Company formerly known as Fairchild Controls Corporation ("Fairchild"). I have worked at this company for the past 20 years. During my first 17 years at Fairchild I held the title of Vice President, Engineering. I have been in my current position for the last three years . Before working at Fairchild, I was employed for 15 years at a different aircraft components manufacturer, Hamilton Standard, now known as Hamilton Sundstrand, where I held the position of Manager, Rotating Machinery. One of the primary components I was responsible for designing and developing during my tenure there were air cycle machines. Including my time at Fairchild, Hamilton Standard, and at Pratt and Whitney Aircraft prior to that, I have over 40 years of professional experience in designing, developing, manufacturing, and repairing aircraft components.

2. My formal education includes a Bachelor of Science in Mechanical Engineering from The Cooper Union in New York, New York (1975); a Masters of Science in Mechanical Engineering and a Masters of Science in Electrical Engineering, both from Rensselaer Polytechnic Institute in Troy, NY. Beyond formal degree education, I have also attended

EXHIBIT
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numerous courses and conferences specifically related to turbomachinery and high speed rotating equipment design.

3. I am submitting this report in support of Fairchild's defenses in *Kenneth Davidson, et al. v. Rockwell International Corp., et al.*, Case No. 4:15-cv-00827; In the U.S. District Court.

B. Air Cycle Machines

4. As the altitude of an aircraft increases in flight, the outside air pressure decreases. Crew and passengers cannot function and breathe normally within an environment having air pressure much lower than that which exists at an altitude of 8000 feet. The FAA therefore requires that cabin pressure be maintained at a pressure no lower than that existing at 8000 feet. This is accomplished by the environmental control system ("ECS") in an aircraft, which delivers pressurized, temperature-conditioned air to the aircraft's cockpit and cabin to ensure adequate levels of ventilation. First, higher pressure air from a higher pressure source (the engine) is introduced to the cabin. Cabin pressure is then maintained at a pressure level that is quite close to that at sea level by carefully modulating the amount of flow permitted to exhaust from the cabin. That air serves as fresh air, ventilation, for the occupants as well, and the FAA requires a minimum volume of fresh air per passenger. Since the bleed air extracted from the engine is hot, having been heated as it passed through the engine's compressor section, it must be cooled before it is distributed throughout the aircraft.

5. The simplest means that could be used to provide climate-controlled, fresh air to an aircraft while in flight is to pass engine bleed air through a heat exchanger which utilizes air outside of the aircraft to remove heat from the engine bleed air. In the heat exchanger, the air can be cooled to a temperature approaching the temperature of the outside air used. Since the bleed

air pressure is higher than the desired cabin pressure, the aircraft cabin pressure can be maintained at an acceptable level by modulating the amount of air allowed to leave the aircraft, using outflow valves. Closing the valves while still supplying the same amount of air will raise the pressure within the cabin, and alternately opening the valves will drop the pressure within the cabin. The temperature of the fresh air introduced into the cabin, however, will be limited by the outside air temperature, the size of the heat exchanger, and the amount of outside air used as coolant within the heat exchanger. If the outside air temperature is higher than the desired cabin temperature, or the heat exchanger used to cool the bleed air or the amount of outside air used for cooling is not large enough to cool the bleed air adequately, the temperature of the fresh air (bleed air) introduced into the cabin will be higher than desired. In addition, it is desirable to introduce much cooler air to remove heat from heat-generating elements within the aircraft, which includes the crew and passengers.

6. The air cycle machine ("ACM") was introduced to solve that problem. Its primary function is to provide cool air to the aircraft at the desired pressure level. The ACM, in combination with the primary and secondary heat exchanger of a typical aircraft cooling pack, performs that function. The ACM is just one component part of the entire ECS on an aircraft.

7. All ACMs rely on the use of high speed turbines. Heat is readily seen as energy capable of doing work. Alternately, when work is performed by a turbine, heat is expended. The relationship between the work performed by a turbine and the heat expended can be expressed as: turbine work is directly proportional to the change in temperature of the air passing through the turbine. Expressed another way, the temperature of air passing through a turbine that is performing work will drop. That is the basic principle utilized by an ACM to cool cabin air. If

the air that is eventually ducted to the cabin passes through a turbine which is doing work, the temperature of the air will drop significantly from the temperature of the air entering the turbine.

8. Another useful relationship associated with turbine driven machines that is less intuitive is as follows: the pressure ratio across the turbine is directly proportional to the temperature ratio across the turbine raised to a known power. By this relationship, a larger temperature difference between the inlet air temperature and the outlet air temperature is obtained when the pressure ratio (the ratio of inlet pressure to outlet pressure) is increased. The pressure at the outlet of the ACM is very nearly equal to the cabin pressure. Consequently, a greater pressure ratio can only be obtained by increasing the pressure of the air entering the turbine. As the inlet air pressure is increased, increasing the pressure ratio, the turbine will expend greater energy and a larger air temperature drop (resulting in lower air temperature leaving the ACM) will be obtained – the cooling capacity will increase.

9. ACMs combine a turbine with one or more power-absorbing components. The first ACMs were turbofans – turbine-driven fans comprised of a turbine mounted on the same shaft as a fan. The power expended by the fan was used to drive outside air through a heat exchanger that cooled bleed air from the engine and then delivered that cooled bleed air to the inlet of the turbine. Since the turbine expended work in driving the fan, the temperature of the air passing through the turbine decreases to a temperature below that of the ambient air that was used to cool the bleed air, and that turbine outlet air was used for cockpit cooling in aircraft including the F-4 Phantom.

10. The next development in ACMs was the turbocompressor, which consisted of a turbine mounted on the same shaft as a compressor. The power expended by the compressor was used to increase the pressure of the bleed air. That higher pressure air was then supplied to the

inlet of the turbine (after removing as much heat as possible using a secondary heat exchanger) and that significantly greater pressure ratio across the turbine dramatically reduced the temperature of the air leaving the turbine. Turbocompressors provide far greater cooling capacity than turbofans. The Twin Commander 690A utilizes a turbocompressor type ACM.

11. The next generation of ACMs incorporated a compressor and a fan driven by a turbine – a three-wheel machine still utilized in many aircraft today including the 747 fleet. The generation after that were designated as four-wheel machines which included two turbines, allowing for water extraction between turbine stages.

C. The Fairchild Air Cycle Machine

12. Between approximately 1950 and approximately 1980, Fairchild manufactured and sold a turbocompressor-type ACM, the ACM Model BUR-20, for use on various types of aircraft.

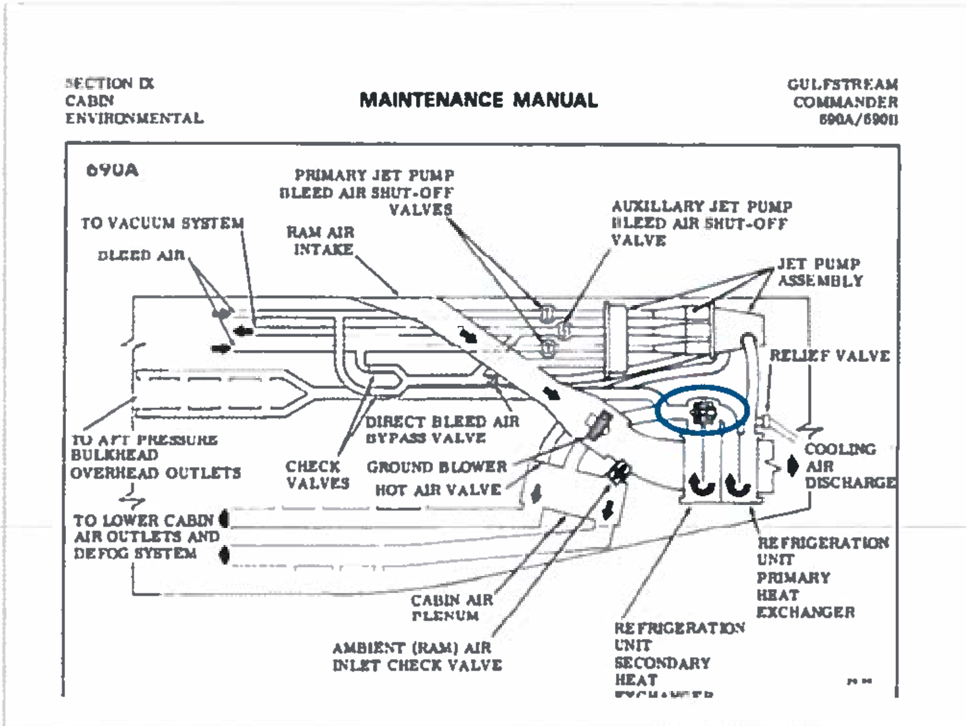
13. Fairchild continues to repair and overhaul used ACM Model BUR-20s at its facility in Frederick, Maryland pursuant to a Parts Manufacturer Approval ("PMA") issued to Fairchild by the Federal Aviation Administration ("FAA") on March 14, 2000, which is attached as Exhibit A to my Report. All repaired or overhauled ACMs are tested and inspected by Fairchild personnel prior to shipment to determine that they have been repaired or overhauled properly.

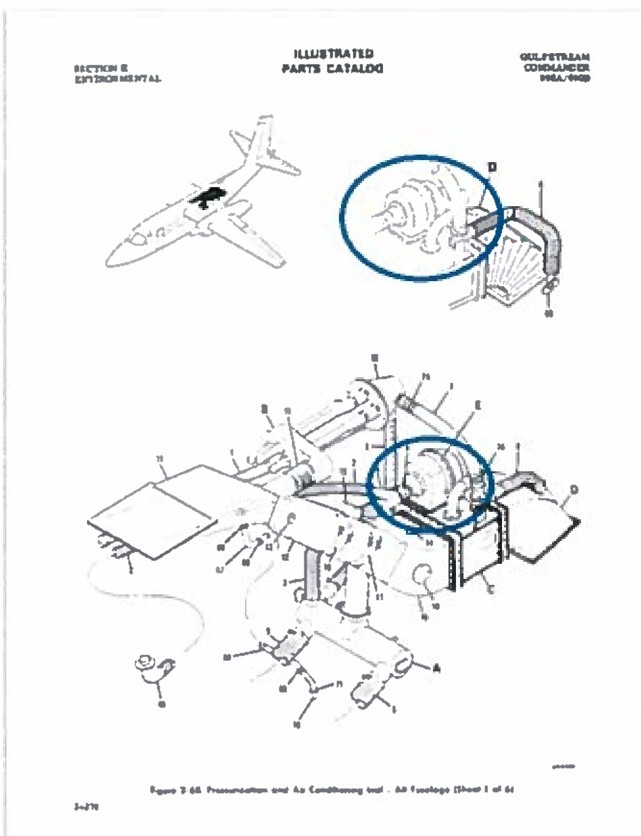
14. One of the aircraft types for which the ACM Model BUR-20 is an approved component is the Twin Commander 690A. The Twin Commander 690A is a turboprop aircraft originally manufactured by Rockwell-Standard & Associates under a type certificate (2A4) issued by the FAA on April 25, 1973. Fairchild did not design or manufacture the Twin

Commander 690A; Fairchild manufactured (and continues to overhaul/repair) ACMs for use in the Twin Commander 690A pursuant to that aircraft's type certificate.

15. The Fairchild ACM that is used on the Twin Commander 690A is a Model BUR-20 ACM, specifically Model Number BUR-20-1D, Part Number 977018. This is a photo of the ACM; this photo also is attached as Exhibit B to my Report:

16. The Fairchild ACM BUR-20-1D, Part Number 977018 also is depicted and described in the Twin Commander 690A Maintenance Manual and in the Twin Commander 690A Illustrated Parts Manual. Two diagrams from those manuals are inserted here with the ACM circled in blue; these diagrams also are attached as Exhibits C and D to my Report.





REPORT OF PAUL DZIORNY

17. Mr. Hansen includes two similar diagrams at Figures 5 and Figure 6 on page 7 of his report (the "Hansen Report"), but he does not identify the ACM component within those diagrams. I include Hansen Report Figures 5 and 6 here as well, with the ACM circled in blue. The component part marked with the blue rectangle is discussed in paragraph 21.

PAI Project: DPHF1402 7 of 18 2016, January 14th

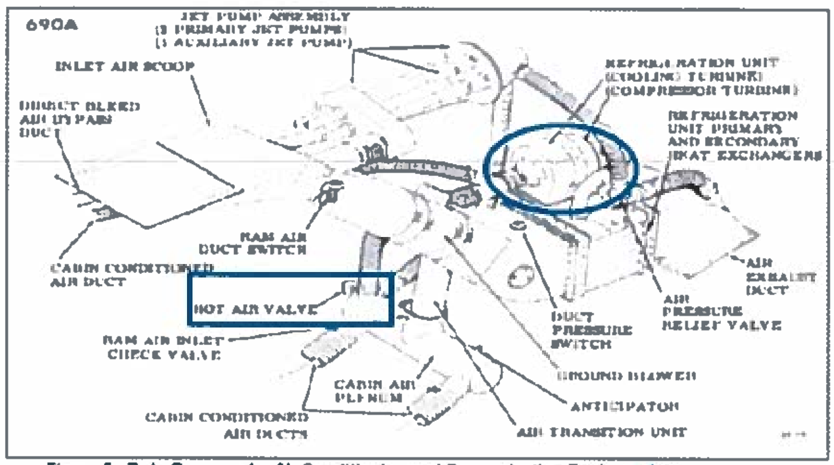


Figure 5 - Twin Commander Air Conditioning and Pressurization Equipment *(Bates # CD03832)*

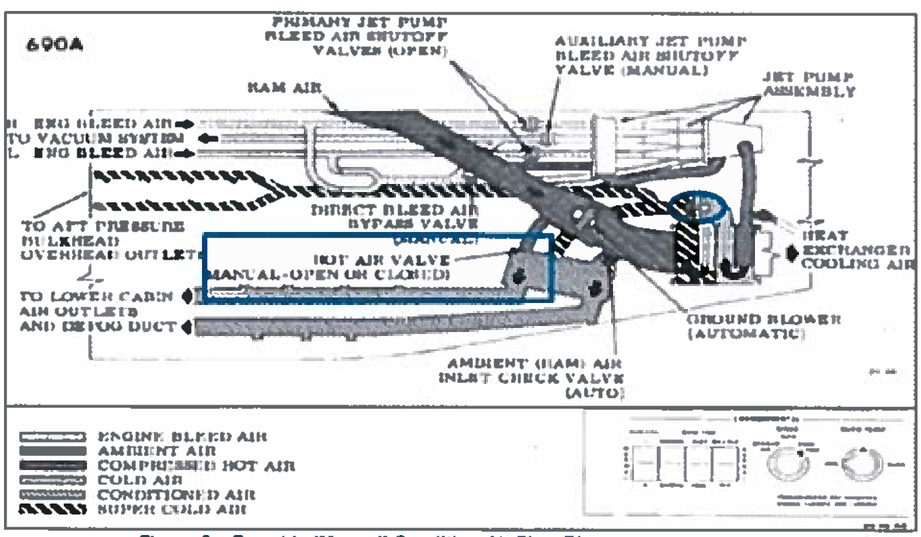


Figure 6 – Override (Manual) Condition Air Flow Diagram *(Bates # CD03847)*

D. The Environmental Control System on the Twin Commander 690A

18. The ECS of the Twin Commander 690A is depicted on the diagrams from the Twin Commander 690A Maintenance Manual and Illustrated Parts Manual, which are inserted in paragraph 16, and the diagrams at Figures 5 and 6 of the Hansen Report, which are inserted in paragraph 17.

19. As shown in those diagrams, on a Twin Commander 690A, the conditioned air distributed to the cabin is a mixture of air that is cooled as it travels through the ACM (as well as other parts of the ECS) and warmer air that bypasses the ACM, *i.e.*, does not pass through the ACM at all. The makeup of that mixture depends on the conditioned air temperature desired. The ECS provides conditioned ventilation air to the cabin and cockpit in the following manner.

a. First, "engine bleed air" (hot, high-pressure air bled from the compressors of the aircraft's engines) is routed through a heat exchanger (the primary heat exchanger), where it is cooled by "ram air" (air drawn from outside the aircraft) which passes through adjacent passages within the heat exchanger.

b. That cooled bleed air then leaves the primary heat exchanger and enters the ACM's compressor. The ACM compressor pressurizes the cooled bleed air to a higher pressure level.

c. That high pressure air then leaves the ACM and passes through the secondary heat exchanger, where the high pressure air is cooled by ram air flowing through adjacent passages of that segment of the heat exchanger.

d. That cooled high pressure air then enters the ACM's turbine. The turbine uses the high pressure air to power the compressor; the process of performing that work further cools the high pressure air because work provided by a turbine is always

accompanied by a temperature decrease of the air performing the work. This process will also produce condensate (water) in the now cooled lower-pressure air, if sufficient humidity exists in the ambient air drawn into the engines.

e. That cooled lower pressure air and any condensate produced then leave the ACM and enter another component part, the water separator, which removes the condensate from the air.

f. The cooled lower-pressure air then enters a mixing chamber designated as the cabin air plenum in the figure above, where, depending on the temperature selected for the cockpit and cabin, it may be mixed with warm bleed air that has come straight from the compressors of the aircraft's engines, bypassing the primary heat exchanger, the ACM, the secondary heat exchanger, and the water separator. Different amounts of the cooled lower pressure air and the warm engine bleed air are mixed to achieve the desired cockpit and cabin temperature. That mixed air then is distributed throughout the cockpit and cabin.

g. Aircraft pressurization is accomplished by outflow/safety valves which regulate the overboard discharge of the conditioned air, and thereby maintain cabin pressure within the aircraft. These valves are not part of the ACM.

20. The Hansen Report also contains a diagram of another, unknown ECS at <u>Figure 2</u> on page 6. <u>Figure 2</u> is misidentified as an "Example Mechanical Flow Diagram for a Common ACM System." I am aware of no aircraft system known as an "ACM system." Also, the ACM in <u>Figure 2</u> is not a turbocompressor-type ACM like the Fairchild ACM Model BUR-20 in the Twin Commander 690A, but instead is a more modern-day ACM commonly referred to as a three-wheel ACM (described in paragraph 11). A copy of Hansen Report <u>Figure 2</u> is inserted

here with the three-wheel ACM circled in blue. The component part marked with a blue rectangle is discussed in paragraph 21.

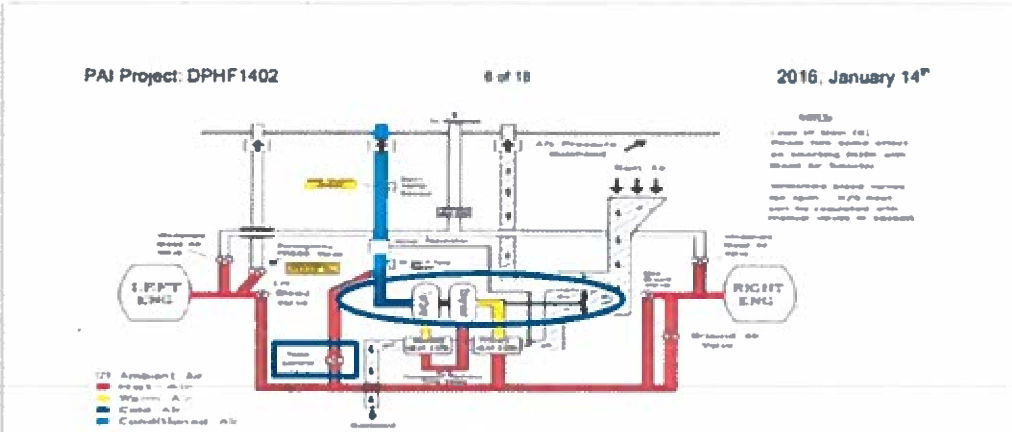


Figure 2 – Example Mechanical Flow Diagram for a Common ACM System

As you can see in Hansen Report Figure 2, the ACM consists of a turbine, compressor, and fan – this is a three-wheel ACM. By contrast, the ACM in the Twin Commander 690A ECS, Fairchild ACM Model BUR-20, employs only a turbine and a compressor. The Twin Commander 690A ECS also utilizes a "ground fan" (shown in the diagrams in paragraphs 16 and 17), but the ground fan is a separate, independent component from and not a part of ACM Model BUR-20. The ground fan's purpose is similar to that of the fan of the three-wheel ACM, however: to draw air through the primary and secondary heat exchangers when on the ground (where no ram air is available since the aircraft is stationary).

21. Hansen Report Figure 2 also shows a "Temp Control Valve," another separate and independent component of the ECS which is identified on Figure 2 in paragraph 18 with a blue rectangle. The Temp Control Valve allows "hot air" (as indicated by the red color and designated as "hot air" in the legend within Figure 2) to bypass the three-wheel ACM and enter the cockpit and cabin as "conditioned air" (as indicated by the blue color and designated as "conditioned air" in the legend within Figure 2). The Twin Commander 690A ECS has a similar

component to the Temp Control Valve, called the "Hot Air Valve," which is identified with blue rectangles on the copies of Hansen Report Figures 5 and 6 that are inserted in paragraph 17. In the Twin Commander 690A, the Hot Air Valve opens automatically when the pilot selects automatic control of cabin temperature and opens manually when the pilot selects manual control of cabin temperature. The Hot Air Valve in the Twin Commander 690A ECS thus allows hot air from engine bleed to bypass the ACM, providing warmer air to the cabin and cockpit after it mixes with cooler air from the ACM. Thus, both the Twin Commander 690A ECS and the unknown ECS in Hansen Report Figure 2 allow bleed air from the engines to bypass the ACM altogether and still be vented to the cabin.

22. Although the Hansen Report includes diagrams of the Twin Commander 690A ECS at Figures 5 and 6, Mr. Hansen nonetheless erroneously concludes on page 4 that: "Unfortunately, the only way for 'clean' outside air to arrive within the cabin is through the Fairchild ACM." (internal quotation marks in original) As explained in paragraph 21 and depicted in the diagrams in paragraphs 16 and 17 (including Hansen Report Figures 5 and 6), the Hot Air Valve of the Twin Commander 690A ECS allows bleed air to bypass the ACM and be vented to the cabin. That happens frequently during flight at higher altitudes, where the air temperature is considerably colder than at sea level, and at all altitudes on cold days.

E. Fairchild ACM Model BUR-20

23. The Fairchild ACM Model BUR-20 is comprised of the compressor section, the turbine section, a bearing cartridge, a shaft, and an oil compartment. The compressor section contains a compressor housing and diffuser and a compressor rotor. The turbine section consists of a turbine inlet housing, a nozzle, a turbine rotor, and a turbine outlet duct. The compressor rotor, the turbine rotor, and the shaft comprise the primary components of the rotating assembly

of the ACM. The rotating assembly is supported by two angular contact ball bearings mounted within the bearing cartridge, with one ball bearing on either end of the shaft. The bearing cartridge is mounted within an intermediate housing that serves as the oil compartment. The oil compartment is filled via an oil fill port tube.

24. The oil compartment holds the required 37 ccs (1.25 fluid ounces, which is equivalent to 2.5 tablespoons) of oil when full. It is filled by adding oil through the oil fill port tube until overflow occurs. Since 37 ccs of oil is contained in the unit when the oil level reaches the top of the oil fill port, the unit cannot be overfilled and cannot contain more than 37 ccs of oil. The compartment itself is larger than that because there is air above the oil in the compartment when the full 37ccs of oil are in the compartment; the position of the oil fill port prevents more than 37 ccs of oil from being poured into the compartment. There is only one oil fill port, and when 37 ccs of oil are present in the compartment, the oil fill port is full to the brim – no more oil can be added.

25. On page 5 of the Hansen Report, Mr. Hansen incorrectly states that: "The only ACM pre-flight check is to '*inspect the refrigeration unit oil filler and maintain oil level at top of filler neck*,' a process that only <u>adds</u> oil into the ACM without an easy way to check if <u>too much</u> oil resides inside the ACM." As explained above, "too much" oil simply cannot be added to the ACM because the design of the oil fill port and the oil compartment ensures that no more than 37 ccs of oil can be present in the oil compartment at any time.

26. The oil compartment contains a wick made of a felt material. The wick extends from the bottom of the oil compartment to the rotating shaft. The wick is immersed in the small quantity of oil contained in the compartment. The oil-laden wick draws the oil from the bottom of the compartment in which it sits and delivers oil to the rotating shaft against which it is

maintained in contact by a spring. A thin film of oil coats the shaft as the shaft rotates past the wick, and that thin film makes its way to the bearings positioned at either end of the shaft as a result of centrifugal force acting on the oil film. The bearings require a bare minimum of oil to provide the thin hydrodynamic film which separates the balls from the races of the bearing, allowing the bearings to function with a minimum amount of friction. This wick-fed oil lubrication system was the state-of-the-art means of lubricating high-speed rotating machinery at the time the ACM was certificated by the FAA and Fairchild began manufacturing it. This method of lubrication remained the state-of-the-art method of lubricating bearings in ACMs through the 1980s, and it remains widely used in ACMs today.

27. The oil compartment also has carbon face seals located on either end and a venting process that prevents leakage from the oil compartment of the ACM during normal operation. The venting process is accomplished through a small bleed hole at the top of the oil compartment which vents to the ambient air through passages that lead from the small bleed hole in the compartment through the outer housing of the ACM, emerging at points along the edge of the oil fill port tube. A photo of ACM Model BUR-20, with the edge of the oil fill port tube where the passages vent from the small bleed hole to the ambient air circled in blue, is inserted here and attached as Exhibit E to my Report.

This venting process maintains the pressure inside the oil compartment at the ambient air pressure in the aircraft compartment in which the ACM is located. Because the pressure inside the oil compartment is maintained at the ambient air pressure, the pressure on the inboard side of each carbon seal (located on either end of the inside of the oil compartment) is always lower than the pressure on the outboard side of each of the carbon face seals (which is where the higher-pressure air that eventually will be ducted to the cabin is located) during operation of the ACM. The lubricity of the carbon seals in combination with the applied pressure differential from outside of the vented compartment to inside of the vented compartment provides the seal that keeps oil within the oil compartment. By design, the positive pressure differential acting at the carbon face seals results in any small leakage proceeding from the higher-pressure air (the air that eventually is ducted to the cabin) *into* the lower-pressure air in the oil compartment, and then through the bleed hole in that oil compartment to the ambient air located in the aircraft compartment where the ACM is located. Consequently oil cannot leak out of the ACM into the ducts that feed air into the cabin during normal operation, since any leakage of airflow is always

into the oil compartment (and then out of the bleed hole to the ambient air in the compartment where the ACM is located) rather than *out of* the oil compartment (and then into the higher-pressure air that is eventually ducted to the cabin).

28. For this reason, Mr. Hansen's statements on page 3 of the Hansen Report that "[a] leaking oil lubricated bearing seal allows some amount of engine oil to be pressured into the air stream," his statement on page 8 that "there will be pressure losses due to viscosity and heat transfer which cause a pressure differential within the shaft/wick space," and his similar suggestions to that effect on pages 6 and 7 are incorrect. Mr. Hansen apparently did not recognize that the oil compartment of the ACM Model BUR-20 (and to my knowledge, that of all ACMs containing oil-lubricated ball bearings) is vented to ambient pressure. As explained above, oil cannot leak from the ACM oil compartment (the "shaft/wick space" Mr. Hansen described on page 8) into the *higher-pressure* air on either side of the oil compartment that will eventually be ducted to the cabin. Air will always flow from high pressure to low pressure. Because of the pressure differential, there is no possibility for oil to leak through the seals into the air that is ducted from the ACM into the cabin during normal operation.

29. Mr. Hansen is similarly incorrect on page 8 of the Hansen Report when he states that "pressure differentials can occur in either direction at various operating conditions, including in-flight turbulence." Turbulence is a normal flight condition; it does not change the pressure differential described above and its effectiveness at preventing oil from leaking from the oil compartment into the higher-pressure air that eventually is ducted to the cabin.

30. There are only two possible ways that oil can "leak" into the air that eventually is ducted to the cabin. The first occurs when the pressure differential described above is not present, and the air that will eventually be ducted to the cabin is not at a higher pressure than the

air in the oil compartment. That occurs when the ACM is not operational, either because the plane is stationary with the aircraft engines off or because no bleed air is being supplied to the ECS. In those situations, then there is a possibility that a very thin film of liquid oil could "weep" through the carbon seals due to gravity alone. That thin film of oil would be virtually undetectable since the oil compartment is not filled to the level at which the seals exist and only the extremely thin film that could exist on the carbon face when operation ceased can possibly exit into the adjacent cavity.

31. The second condition is one in which a bearing fails. When a bearing's life is used up and a bearing failure occurs, the extreme motion of the shaft which is normally supported by the bearings can result in carbon seal failure. With the large frictional drag forces that occur during a bearing failure, the rotation of the machine stops almost instantly – typically within a fraction of a second. High pressure air still exists in the ACM cavities adjacent to the oil compartment, but the bleed hole will be overwhelmed by the volume of air that enters the oil compartment upon seal failure, and hot air can flow through the oil compartment (which is no longer sealed after a failure has occurred) to the opposite side of the oil compartment and into the cabin air ducting. Consequently, following a bearing failure, hot air can mix with the small quantity of oil within the oil compartment and oil fumes can enter the conditioned air ducting. That occurrence is extremely short-lived due to the small quantity of oil that exists and would occur immediately upon the failure of a bearing in the ACM. A bearing failure is typically detected immediately as cool air can no longer be produced, and the ACM will usually be replaced at the next airport where maintenance and a replacement is available. Bearing failure is by no means a chronic or continuous occurrence; once a bearing has failed, the ACM does not

function at all. A bearing failure could not produce the long or continued, repeated fume events described by the plaintiffs in this case.

F. Oil-Lubricated Bearing ACMs and Air-Bearing ACMs

32. Although some later generations of ACMs incorporated "air bearings" that do not use lubricating oil, that redesign was done to reduce maintenance and improve reliability, not to improve safety.

33. ACMs with oil-lubricated bearings ("oil-lubricated bearing ACMs"), like the Fairchild ACMs, cannot be "retrofitted" with air bearings, because air-bearing ACMs are designed completely differently than oil lubricated bearing ACMs. Air-bearing ACMs utilize two independent journal bearings and a separate thrust runner with thrust bearings mounted on either side of a rotating disk. Air-bearing ACMs require a much larger diameter shaft than the oil-lubricated bearing ACMs, because a larger shaft is necessary to support the loads carried by the journal bearings and the thrust runner. The bearings in an air-bearing ACM must be cooled by ducting air from the turbine inlet housing to each of the bearings, which also then requires labyrinth-type air seals be used to segregate that high pressure air from adjacent compartments, whereas oil-lubricated bearing ACMs have a single vented bearing compartment.

34. As a result, it would be impossible to refit the ECS of a Twin Commander aircraft with an air-bearing ACM. An air-bearing ACM is a total unit redesign, not a retrofit of bearings. I am not aware of any customer request that would authorize a redesign of that nature, nor am I aware of any existing supplemental type certificate that would allow use of such a redesign (and a supplemental type certificate would be required for Fairchild or any manufacturer to offer a redesigned ACM).

G. The ACM Has Not Been the Subject of Airworthiness Directives or Complaints

35. From time to time, the FAA issues Airworthiness Directives to correct unsafe conditions in aircraft products, including engines, propellers, and other components. The FAA compiles and maintains a publicly-accessible database of Airworthiness Directives at http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAD.nsf/MainFrame?OpenFrameSet. To my knowledge, the Fairchild ACM has never been the subject of any Airworthiness Directive. Until it was served with this lawsuit, Fairchild had never received any complaints about bleed air contamination issues allegedly related to its ACM.

36. Other than the specific incident involving the Plaintiffs in this case, I am unaware of any other complaints about so-called "bleed air contamination" involving a Fairchild ACM and a review of Fairchild's records revealed no such complaints.

H. The ACM Is Not a Filter and Does Not Clean or Safeguard Cabin Air

37. The Fairchild ACM is not designed or intended to detect, filter, or remove contaminants from bleed air or from the aircraft's air conditioning system. For this reason, Fairchild has never marketed, advertised, or represented the Fairchild ACM as an effective device for detecting, filtering, diverting, or removing contaminants from bleed air or from the aircraft's air conditioning system. I am not aware of any ACM manufactured by Fairchild or any other manufacturer that incorporates a HEPA or other type of filter or a contaminant-detection sensor. Although such a filtration or detection function might be desirable as part of an aircraft or ECS, Fairchild did not design or manufacture the Twin Commander 690A and was not responsible for incorporating components capable of performing such functions.

38. Based on my familiarity with the Fairchild ACM and my more than 40 years of experience as an engineer specializing in the manufacture and refurbishment of air cycle

machines and other aircraft components, it would not be feasible to incorporate or retrofit a filtration or sensor component into the Fairchild ACM for a number of reasons.

a. First, a filter requires a nearly quiescent environment to be effective. The velocity of the air approaching the filter must be maintained at very low levels. The velocity of air is related to the amount of airflow and the size of the duct through which that air passes. The turbine outlet duct of the ACM is the airflow exit passage from the ACM. It is too small to incorporate a filter, since the velocity of air passing through that duct is too high to allow for adequate filtering without excessive pressure drop across the filter. A photograph of the ACM illustrating this point is inserted here and attached at Exhibit F to my Report:

The green duct with the orange cap is the exhaust port (turbine outlet) of the ACM, containing moderately high velocity air – the velocity of air existing within that duct is too high to incorporate a filter without excessive detriment to the cooling performance of the ACM – its primary function

b. In addition, the ACM is a relatively small component and does not have sufficient space to incorporate a filter robust enough to remove contaminants from the

bleed air without excessive pressure loss that would affect the amount of air as well as the cooling performance of the ACM. A sensor would be difficult to fit inside the ACM for the same reasons.

c. The ACM also sometimes exhausts condensate mist – small droplets or mist of condensed water. This occurs whenever the aircraft is flying in a humid air environment. That mist would be collected on the filter if it were installed downstream inside the ACM and would result in further unacceptable pressure drop and/or deterioration of the filter element. That mist also would be collected on a sensor, which could impede or prevent the sensor from detecting contaminants in the air.

d. Finally, a filter or sensor in the ACM would not filter or detect any contaminants from bleed air that does not pass through the ACM. In a Twin Commander 690A, it would not filter or sense all bleed air when warm air is required since some bleed air is ducted directly from the compressors of the aircraft's engines and does not pass through the ACM. The ACM is a component in the middle of one branch of the ECS, and consequently a filter or sensor located there will not ever filter or sense all of the air entering the cabin. For that reason, the addition of a filter or sensor would most appropriately be incorporated outside of the ACM and downstream of the rest of the ECS, as a separate line replaceable unit that could also then be readily maintained.

39. Additionally, incorporating a filtration device or toxin sensor into the Fairchild ACM would require a complete redesign of that component, which has been out of production for more than 20 years and has limited and declining demand. As a result, even apart from the technical challenges described above, it would be economically unfeasible to incorporate a filtration device or toxin sensor into the Fairchild ACM.

I. Fairchild's Repair and Overhaul of Used Air Cycle Machines

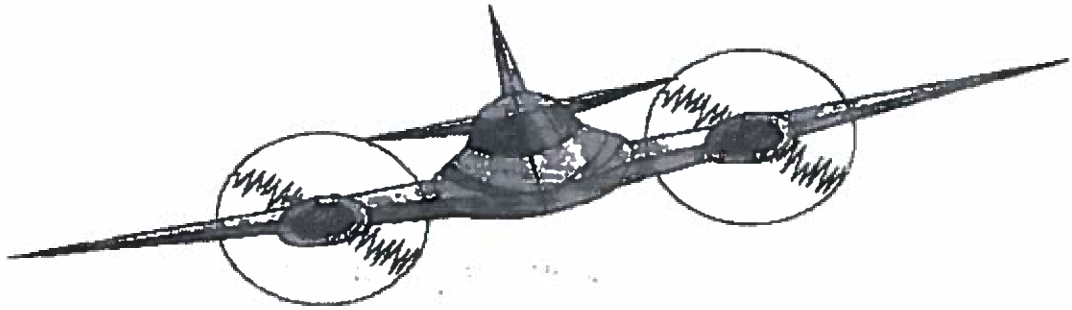
40. Fairchild no longer manufactures or sells new ACMs for the Twin Commander 690A or other aircraft. Although Fairchild no longer manufactures new ACMs, numerous aircraft utilizing Fairchild ACMs (including the Twin Commander 690A and its variants) remain in service. As a result, there remains an active, though diminishing, market for replacement Fairchild ACMs.

41. To ensure a supply of airworthy replacement ACMs, Fairchild repairs and overhauls used ACMs at its facility in Frederick, Maryland pursuant to a Parts Manufacturer Approval ("PMA") issued to Fairchild by the Federal Aviation Administration ("FAA") on March 14, 2000. The PMA is attached as Exhibit A to my Report. The March 14, 2000 PMA reflects the FAA's determination that the design of the repaired Fairchild ACM, Part No. 977000-2 Revision A, "meets the airworthiness requirements of the FARs [Federal Aviation Regulations] applicable to the" Twin Commander 690A, and that "Fairchild Controls Corporation has established the fabrication inspection system required by FAR 21.303(h) at 540 Highland Street, Frederick, Maryland." The PMA is available on the FAA's online database at: http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgPMA.nsf/0/108E0CC01764ED85862578 F5005F320F?OpenDocument. Under this PMA, Fairchild is not permitted to make any changes to the ACM's design without obtaining prior authorization from the FAA itself.

Paul J. Dziorny 3/4/16

Paul Dziorny
Vice President, Chief Engineer
Triumph Thermal Systems—Maryland

Exhibit A



Federal Aviation Administration
ANE-MIDO-44
400 Airport Drive
Bldg. 201, Rm. 102
New Cumberland, PA 17070-3419

To: Walt Sparks

Phone: 301-228-3414
Fax: 301-682-6885

From: Richard Piper

Phone: 717-782-4425
Fax: 717-782-2231
E-mail: rick.piper@faa.gov

Date: 3/15/00
Time: 6:25 AM

Pages including this cover page: 3

Comments:

Mr. Sparks,

Please consider this your PMA Approval Supplement 05-F. The original is in the mail.

Please do not hesitate to contact this office if any questions arise or if we can be of any further assistance.

Regards,
Rick

Geographic Area Served: The states of Maryland, Virginia & West Virginia, the District of Columbia, and the state of Pennsylvania.

U.S. Department of Transportation
Federal Aviation Administration

New England Region
Manufacturing Inspection District Office #44

Bldg. 201 Room 102 400 Airport Drive
New Cumberland PA 17070-3419
(717) 782 4425 FAX: (717) 782 2231

March 14, 2000

Mr. Walter Sparks
Director of Quality Assurance
Fairchild Controls Corporation
540 Highland Street
Frederick, MD 21701

Dear Mr. Sparks:

FEDERAL AVIATION ADMINISTRATION - PARTS MANUFACTURER APPROVAL

In accordance with the provisions of Federal Aviation Regulation (FAR) 21, Subpart K, we have found that the design data, submitted by Fairchild Controls Corporation by letter on March 8, 2000 meets the airworthiness requirements of the FARs applicable to the products on which the parts are to be installed. Additionally, it has been determined that Fairchild Controls Corporation has established the fabrication inspection system required by FAR 21.303(h) at 540 Highland Street, Frederick, Maryland. Accordingly, Parts Manufacturer Approval (PMA) is hereby granted for production of the replacement parts listed in the enclosed Supplement Number 05-F in conformity with the applicable Federal Aviation Administration (FAA) approved design data.

You are reminded that provisions of the FARs noted in our PMA letter of November 10, 1993, Supplement No. 01-F, also apply to the enclosed PMA listing - Supplement Number 05-F.

Sincerely,

Richard R. Pigozzi
for Stacy L. Ratliff
Manager

Enclosure
PMA Supplement 05-F

FEDERAL AVIATION ADMINISTRATION – PARTS MANUFACTURER APPROVAL

FAIRCHILD CONTROLS CORPORATION
540 HIGHLAND STREET
FREDERICK, MARYLAND 21701

PMA NO. P0932NED
SUPPLEMENT NO. 05-F
DATE March 14, 2000

Part Name	Part Number	Approve Replacement For Part Number	Approval Basis and Approved Design Data	Make Eligibility	Model Eligibility
Cooling Package BUR 20-1D	977000-2 Revision A	Twin Commander P/N 977000-2	Identicality per 14 CFR 21.303, licensing, Agreement between Twin Commander Aircraft Corp. and Fairchild Controls Corp. File No. TCAC-00-010 Dated 2/28/2000 TC: 2A4 Drawing: 88052 Rev: R Date: 8/25/78 Or later FAA approved Revisions	Twin Commander	690A, 690B 690, 685, 681 680W, 680T 680FL(P), 720

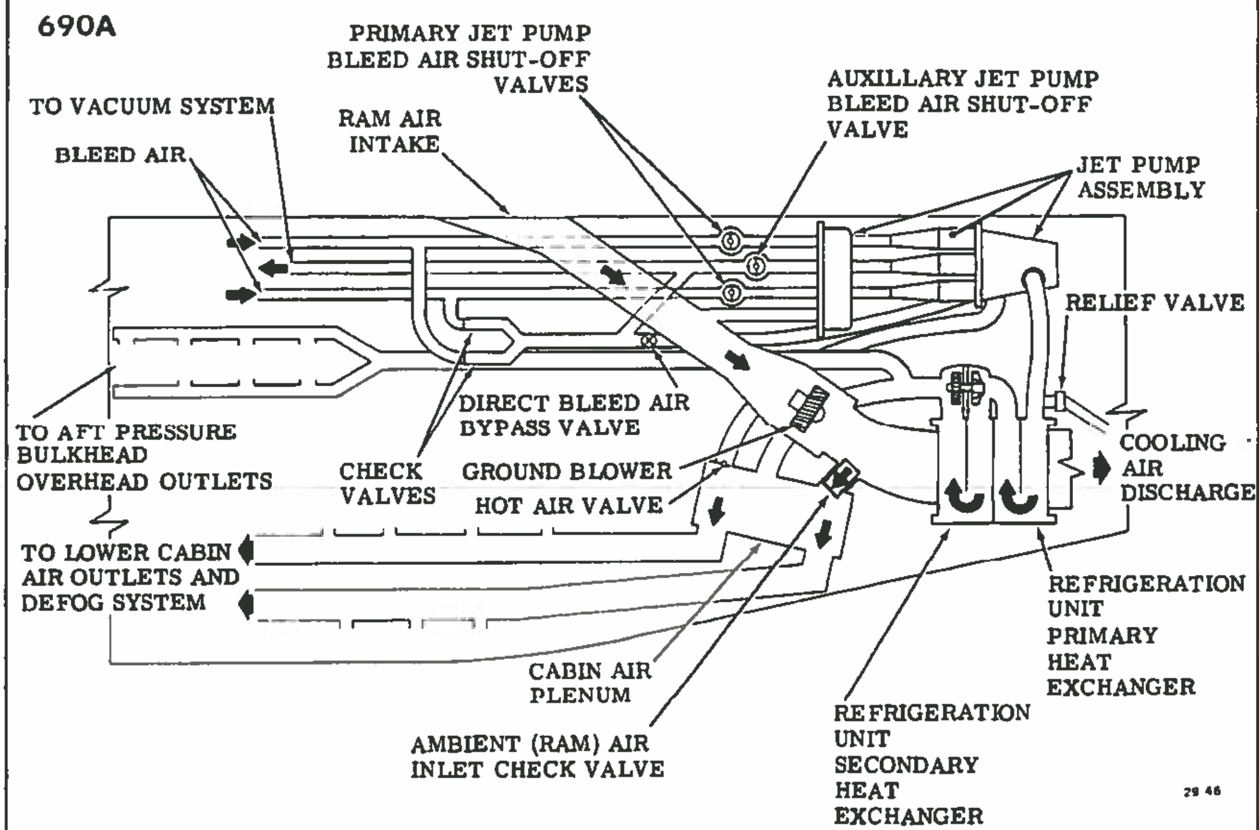
------------------------------ End of Listing ------------------------------

Note: The procedures that have been accepted by the type certificate or TSOA holder and their cognizant FAA Aircraft Certification Office, for minor changes to original parts used on type certificated products, are also acceptable for incorporating the same minor changes on identical FAA-PMA replacement parts. The FAA-PMA holder shall be able to show traccability relating to the TC, STC, or TSOA holder on all minor changes incorporated by this procedure. When these procedures are no longer applicable because of completion of the production contract, or termination of the licensing agreement or Business relationship, all subsequent minor design changes to the PMA parts must be submitted in a manner as determined by the ACO. Minor design changes (reference 14 CFR Part 21 §§ 21.93 and 21.97) to drawings and specifications are to be handled in the same manner as that for and original FAA-PMA.

Richard R. Piper for S.L. Ratliff
Manager, Manufacturing
Inspection District Office

Exhibit B

Exhibit C



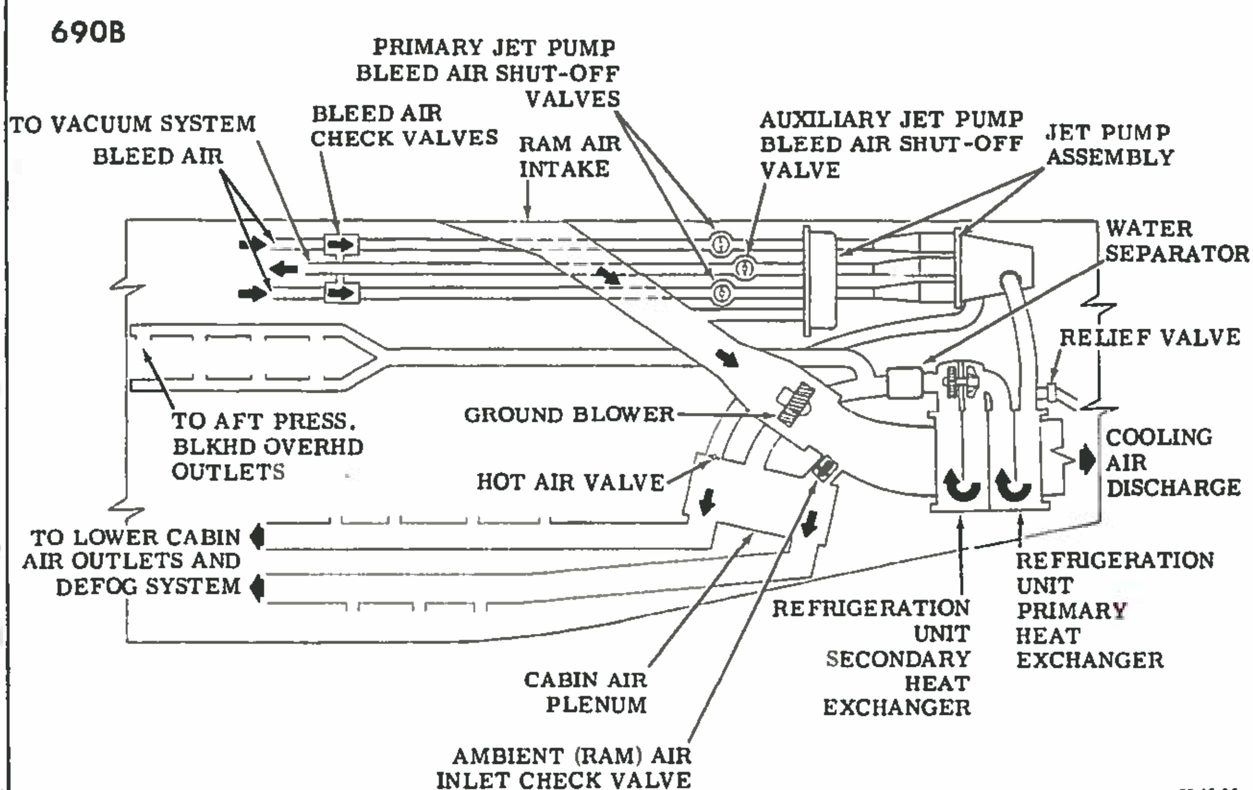


Figure 9-3. Air Supply and Distribution

Exhibit D

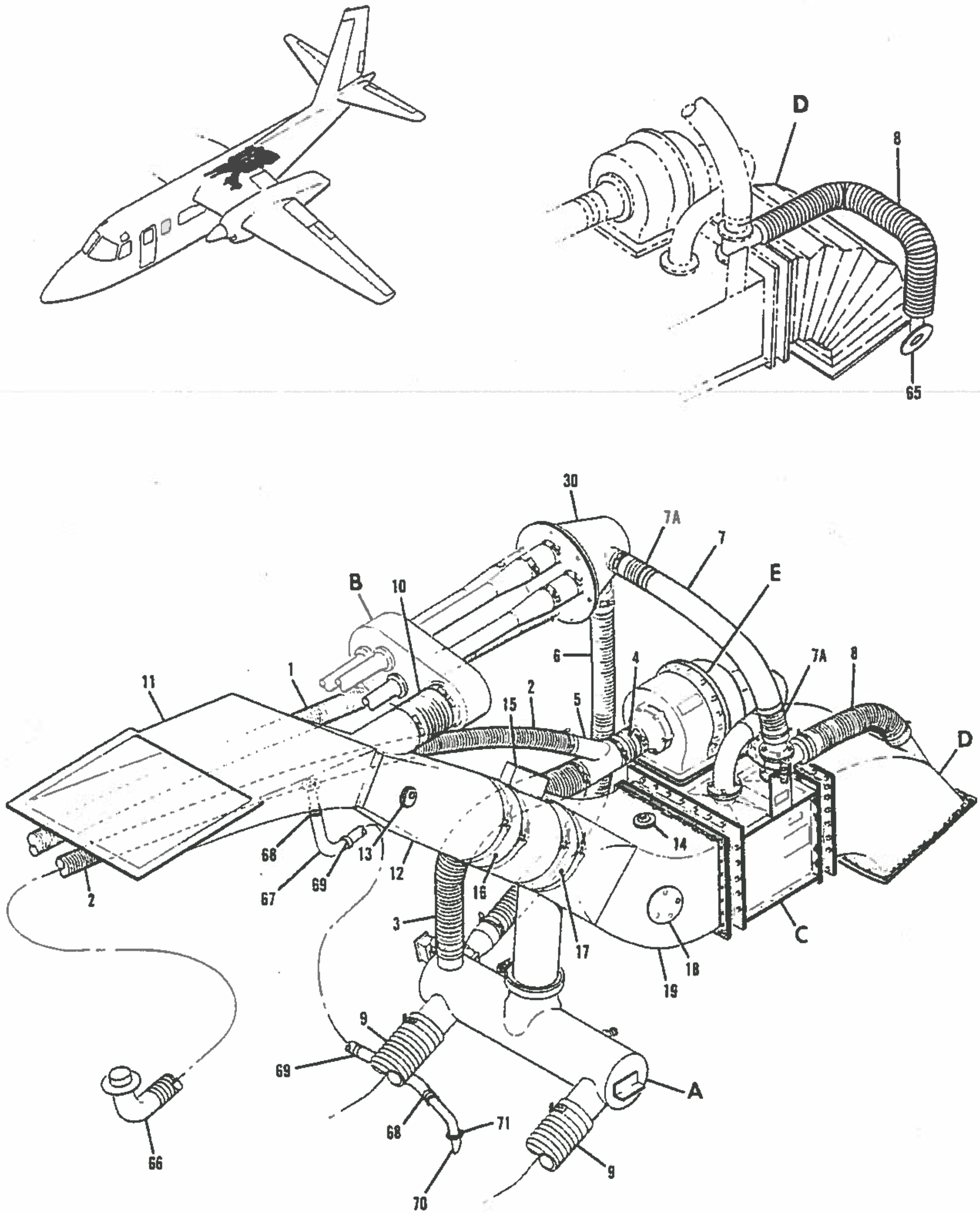


Figure 2-68. Pressurization and Air Conditioning Instl - Aft Fuselage (Sheet 1 of 6)

Exhibit E


NOTICE

Exhibit F

The green duct with the orange cap is the exhaust port (turbine outlet) of the ACM, containing moderately high velocity air – the velocity of air existing within that duct is too high to incorporate a filter without excessive detriment to the cooling performance of the ACM – its primary function

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his testimony.

THE WITNESS:

I didn't say all. That's a big word too. I made a quick read through and the stuff that came to mind. I said I may have more later I just don't right now.

BY MR. ODELL:

Q. Okay. As you sit here today in your deposition, you've identified all of the objections or disagreements you have with the two of them that you are aware of, correct?

A. Basically that I'm aware of by just quick reading and telling you the answers, that's the best I can do right now.

Q. And have you been asked to prepare or undertake any kind of a rebuttal report either to Mr. Dziomy or Mr. Lykens' reports?

A. No.

Q. Is there any remaining work that you've been asked to do in this case that you have not yet completed?

A. No.

MR. MITCHELL:

Object to form. Just to any extent it ask for what trial strategy we have may

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have.

MR. ODELL:

I didn't ask about any of those things.

BY MR. ODELL:

Q. Mr. Hansen, that's all I've got for you this afternoon.

A. Okay.

Q. Thank you for your time.

A. You're welcome.

(DEPOSITION WAS CONCLUDED AT 3:02 P.M.)

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WITNESS CERTIFICATE

I, DON HANSEN, do hereby certify that the foregoing testimony was given by me, and the transcription of said testimony, with corrections and/or changes, if any, is true and correct as given by me on the aforementioned date.

2016, MAY 18 Don Hansen

DATE SIGNED DON HANSEN

Signed with corrections as noted. ✓

~~Signed with no corrections as noted.~~

DATE TAKEN: 3/22/16

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REPORTER'S PAGE

I, CYNTHIA M. GRIJALVA, Certified Court Reporter, in and for the State of Louisiana, the officer before whom this sworn testimony was taken, do hereby state:

That due to the spontaneous discourse of this proceeding, where necessary, dashes (--) have been used to indicate pauses, changes in thought, and/or talkovers; that same is the proper method for a Court Reporter's transcription of a proceeding, and that dashes (--) do not indicate that words or phrases have been left out of this transcript;

That any words and/or names which could not be verified through reference material have been denoted with the phrase "(phonetically spelled)."

CYNTHIA M. GRIJALVA, CCR, RPR

ERRATA SHEET

Deposition of: Donald E. Hansen

I wish to make the following changes for the following reasons:

Page	Line	Change	Reason
8	2	AMP to: A & P	Correction
8	13	Heart to: Harvard	Correction
11	18	AMP to: A & P	Correction
13	21	TCM to: TCP	Correction
15	20	Engine to: Engine oil	Clarification
28	12	Fudge to: Feucht	Correction
51	9	bleed to: blade	Correction
57	11 & 13	PAI8 to: PAI-8	Correction
59	4	offense to: occurance	Correction
66	1	Myself to: ??	Correction
66	10	Look to: looks	Correction
75	3	Auto to: Otto	Correction
86	17	Pacific to: Cedric	Correction

Witness Name (Printed): Donald E. Hansen

Witness Signature: Donald E. Hansen

Date: 2016, May 18

ERRATA SHEET

Deposition of: Donald E. Hansen

I wish to make the following changes for the following reasons:

Page	Line	Change	Reason
99	22	close to: choose	Correction
101	9	subjective to: subjected to	Correction
125	9	paraplan to: power plant	Correction
127	15	past to: pass	Correction
134	21	bluey lips to: blue ellipse	Correction
135	20	he follows it and to: it follows at	Correction
136	2	mechanic for a common to: mechanical flow diagram	Correction
137	7	amount to: mount	Correction
137	16	tubbing to: tubing	Correction
139	25	substantially to: obstensibly	Correction
143	10	fill to: wick	Correction
143	19	life to: professional life	Correction
151	24	In 40 to: In his 40	Clarification

Witness Name (Printed): Donald E. Hansen

Witness Signature: Donald E. Hansen

Date: 2016, May 18